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FINAL REPORT ADDENDUM

FLIGHT PROTOTYPE CO_2 AND HUMIDITY CONTROL SYSTEM

BY

KAREN M. RUDY

PREPARED UNDER CONTRACT NO. NAS9-13624

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HAMILTON STANDARD
DIVISION OF UNITED TECHNOLOGIES CORPORATION
WINDSOR LOCKS, CONNECTICUT

FOR

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LYNDON B. JOHNSON SPACE CENTER
HOUSTON, TEXAS

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ABSTRACT

A regenerable CO_2 and humidity control system is presently being developed for potential use on Shuttle as an alternative to the baseline lithium hydroxide (LiOH) system. The system utilizes a sorbent material (designated "HS-C") to adsorb CO_2 and the latent heat load from the cabin atmosphere and desorb the CO_2 and water vapor overboard when exposed to a space vacuum, thus reducing the overall vehicle heat rejection load. Continuous operation is achieved by utilizing two beds which are alternately cycled between adsorption and desorption.

The HS-C material process was verified with the fabrication and system testing of approximately fifty pounds of sorbent. The structural integrity of the HS-C material was demonstrated by subjecting the material in its alumuninum foam environment to a simulated Shuttle vibration loading.

Design concepts for the auxiliary components for the HS-C prototype system were generated. Shuttle qualified or Aircraft Components were chosen for the fan and valving requirements. New hardware will be required for the ullage compressor and electronic controller.

Performance testing verified system effectiveness in controlling CO_2 partial pressure (PCO_2) and humidity. The effect of specific parameters such as air flow and temperature, cycle time, PCO_2 and dew point was investigated. The effect of vacuum desorption levels on system CO_2 and water removal capacity was also studied. Testing with a single bed operating showed that the degraded system can maintain an acceptable PCO_2 level for a four-man crew.

FOREWORD

This report has been prepared by Hamilton Standard, Division of United Technologies Corporation, for the National Aeronautics and Space Administration's Lyndon B. Johnson Space Center in accordance with Contract NAS9-13624, "Breadboard and Flight Prototype CO_2 and Humidity Control Systems." This addendum covers work accomplished on the flight prototype phase of the program between November 1, 1977 and December 31, 1978. This report supplements the Final Report, SVHSER 7182, published September, 1977. Work on the breadboard system was described in the Interim Report, SVHSER 7103, published October, 1976.

Appreciation for the current effort is expressed to the Technical Monitor, Mr. Frank Collier and to Mr. L. D. Kissinger of the NASA, Johnson Space Center, for their guidance and advice.

This program was conducted under the direction of Mr. Harlan F. Brose, Program Manager, and Ms. Karen M. Rudy, Program Engineer, with the assistance of Mr. John F. Gruber, Design, and Mr. Albert Boehm and Mr. Gilbert N. Kleiner, Project.

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SUMMARY

Development of the flight prototype system was extended with the addition of four tasks: material fabrication, module vibration, design concepts, and performance testing.

Two new batches of HS-C sorbent material were fabricated; batch one with new substrate and four-year-old PEI-18 and batch two with new substrate and new PEI-18. The fabrication of this fifty-four pounds of HS-C sorbent and subsequent performance testing verified that the process could be duplicated with consistent results.

The HS-C material, packed in a module incorporating the aluminum duocell foam, was subjected to a simulated Shuttle vibration loading. No evidence of physical damage or powdering of the HS-C beads was observed when examined under a 200X microscope.

The design concepts for the auxiliary components for the prototype system were reviewed and a vendor search initiated. Available shuttle and aircraft components were selected for the process fan, pressure equilization valves, emergency vacuum shutoff valve, and bypass valve. It was determined that the ullage-save compressor and the controller require design and development.

Performance testing demonstrated that the HS-C material fabricated in 1974 provided acceptable CO_2 and humidity levels in a simulated Shuttle volume. The system test was repeated with the newly fabricated HS-C, resulting in a 15% improvement in CO_2 absorption over the performance of the four-year-old material. Parametric testing of the system was also undertaken to evaluate the effect of cycle time, air temperature, air flow, CO_2 partial pressure, and dew point.

Vacuum desorption testing showed that the bed vacuum level during desorption has a strong effect on CO_2 and water removal rates. Single bed testing, simulating one bed operation, demonstrated that the system could maintain an acceptable CO_2 level for a four-man crew.

INTRODUCTION

A regenerable CO_2 and humidity control system is being developed for potential use on Shuttle as an improvement to the baseline Lithium Hydroxide (LiOH) and condensing heat exchanger system especially for extended duration missions. The system uses a sorbent material (designated "HS-C") to adsorb CO_2 and water vapor from the cabin atmosphere. The CO_2 and water vapor are subsequently desorbed overboard when exposed to the space vacuum. Continuous adsorption from the cabin and desorption to space is achieved by utilizing two beds which are alternately cycled between adsorption and desorption. The heat of adsorption is passed to the desorbing bed thus regenerating the beds in a nearly adiabatic process. As a result, the HS-C system removes the latent and CO_2 heat loads from the cabin heat exchanger and reduces the overall vehicle heat rejection load. The HS-C system is especially desirable because it requires only three interfaces; space vacuum, electrical, and air distribution.

The present program, NAS 9-13624 was designed to develop unique HS-C components and test a flight prototype system to simulated Shuttle mission profiles.

The HS-C sorbent material was developed and reported in previous programs, NAS9-11971 and NAS9-12957. A breadboard system was fabricated and tested during the first phase of the present program and reported in the Interim Report, SVHSER 7103, October, 1976. A flight prototype phase of the program was described in the Final Report, SVHSER 7182, September, 1977.

This report, an addendum to the Final Report, includes additional performance testing of the prototype system. The report presented herein describes the fabrication of a new batch of HS-C sorbent material, the testing of this material in the prototype system, the vibration of a small scale module to evaluate the material, and the concepting of the major auxiliary components required to complete the HS-C system.

The calculations in this report were made in US customary units and converted to SI metric units.

OBJECTIVES

The program was divided into four tasks: HS-C Material Fabrication, Module Vibration, Design Concepts, and System Performance Testing. The objectives of each task are listed below.

HS-C MATERIAL FABRICATION

- To verify the repeatability of the fabrication process.
- To evaluate the effect of aging of the PEI-18 coating prior to making the HS-C material.

MODULE VIBRATION

- To demonstrate the structural integrity of the HS-C material when packaged in the aluminum foam.
- To evaluate the effect of bed preload on the HS-C material when subjected to vibration loads.

DESIGN CONCEPTS

- To formulate a design concept for unique HS-C system components.
- To initiate a vendor search to determine if the components are available commercially.
- To determine which system components must be specifically developed for the HS-C application.

SYSTEM PERFORMANCE TESTING

- To determine the effect of age and previous use of the HS-C sorbent material on system performance.
- To demonstrate CO_2 and humidity control performance of the newly-fabricated HS-C material.
- To determine the effect of vacuum desorption levels on system performance.

CONCLUSIONS

1. Material fabrication and subsequent testing has demonstrated that the fabrication process can be duplicated with consistent results.

2. The effect of shelf age of PEI-18 on the HS-C sorbent fabricated has been shown to be negligible.

3. Performance testing has shown no significant difference between new HS-C material coated with four-year-old PEI-18 and new material coated with new PEI-18.

4. Vibration testing has demonstrated that bed preload has no physical effect on the HS-C material subjected to vibration loading.

5. The HS-C material packaged in aluminum duocell foam exhibits no physical powdering or damage after undergoing a simulated Shuttle vibration loading.

6. Shuttle qualified or Aircraft components will satisfy the system requirements for the process fan, pressure equilization valves, and vacuum shutoff valve.

7. The ullage-save compressor and the controller for the HS-C system will require new hardware.

8. Performance testing has demonstrated that the prototype system filled with four-year-old HS-C material provides complete CO_2 and humidity control for Shuttle application.

9. Testing simulating a vacuum valve failure has demonstrated that the prototype system with a single bed mode of operation can maintain acceptable CO_2 levels for a four-man crew.

10. Desorption vacuum pressures were shown to have a significant effect on HS-C system performance.

RECOMMENDATIONS

1. The HS-C material fabricated in 1978 should be retested in three years. This will determine if the 15% improvement in performance is the result of batch variations or material aging.

2. The design and development of the ullage-save compressor and the controller should be initiated.

3. A packaging layout drawing should be prepared defining the installation of the ancillary components in the HS-C prototype system.

4. The flight prototype system should be updated to incorporate the ancillary components such as the process fan, pressure equilization valves, compressor, and controller.

5. The flight prototype canister design should be modified to incorporate larger fill ports.

6. The fabrication of a second flight prototype canister should be performed in order to further demonstrate the manufacturing technique.

7. The HS-C system should undergo additional performance testing to more clearly define the effects of inlet dew point and air temperature on CO_2 removal performance.

8. Bed filling techniques should be investigated to confirm that bed preload is not required.

9. An Optimization Study to evaluate the effect of the control methods of automatic bypass of flow, selective fan operation and variable cycle length should be conducted.

DISCUSSION

The efforts described herein satisfy the additional requirements per Modification 20S to the contract. The added tasks are Material Fabrication, Module Vibration, Design Concepts, and Performance Testing. All tasks are presented in the following subsections in the order listed above.

MATERIAL FABRICATION

The objective of this task is to manufacture approximately forty pounds of HS-C material. This will verify that the process can be duplicated with consistent results and can be tested in the flight prototype system to evaluate material age versus system performance.

Material fabrication was initiated per the procedure established previously in 1973-1974. The substrate, Amberlite XAD-7, was dried and then sieved to obtain the desired particle size. The batch of substrate purchased initially had an unexpectedly low yield of 30-40 mesh particles. Fabrication was delayed until a better batch could be obtained from the vendor.

To expedite material fabrication, a vacuum rotary dryer was rented. The setup, shown in Figure 1 , consisted of a rotary dryer with a variable speed motor and with a double jacketed chamber to maintain the desired temperature. The setup also included a condensing column and a vacuum pump. The fabrication procedure was modified to optimize material production using this equipment. The dryer setup was used for drying, washing, and vacuum coating of the beads.

The Amberlite beads were dried and sieved to obtain the desired bead size. The substrate was washed with distilled water, and subsequently with methanol, using a revised washing approach that saved processing time. The Amberlite was placed in the rental dryer and washed with distilled water. The conductivity of the effluent water was measured after each wash cycle; the process was repeated in the rotary dryer until the conductivity was minimized. The substrate was washed with methanol, and then coated with PEI-18. Two batches of HS-C material were fabricated; namely, new substrate coated with four-year-old PEI-18, and new substrate coated with new PEI-18. Approximately 27 pounds of each batch were produced. The coated substrate was sieved again to assure the correct particle size.

It should be noted that the use of the vacuum rotary dryer expedited the fabrication process. The procurement of this equipment would greatly improve the production of large quantities of the HS-C material.

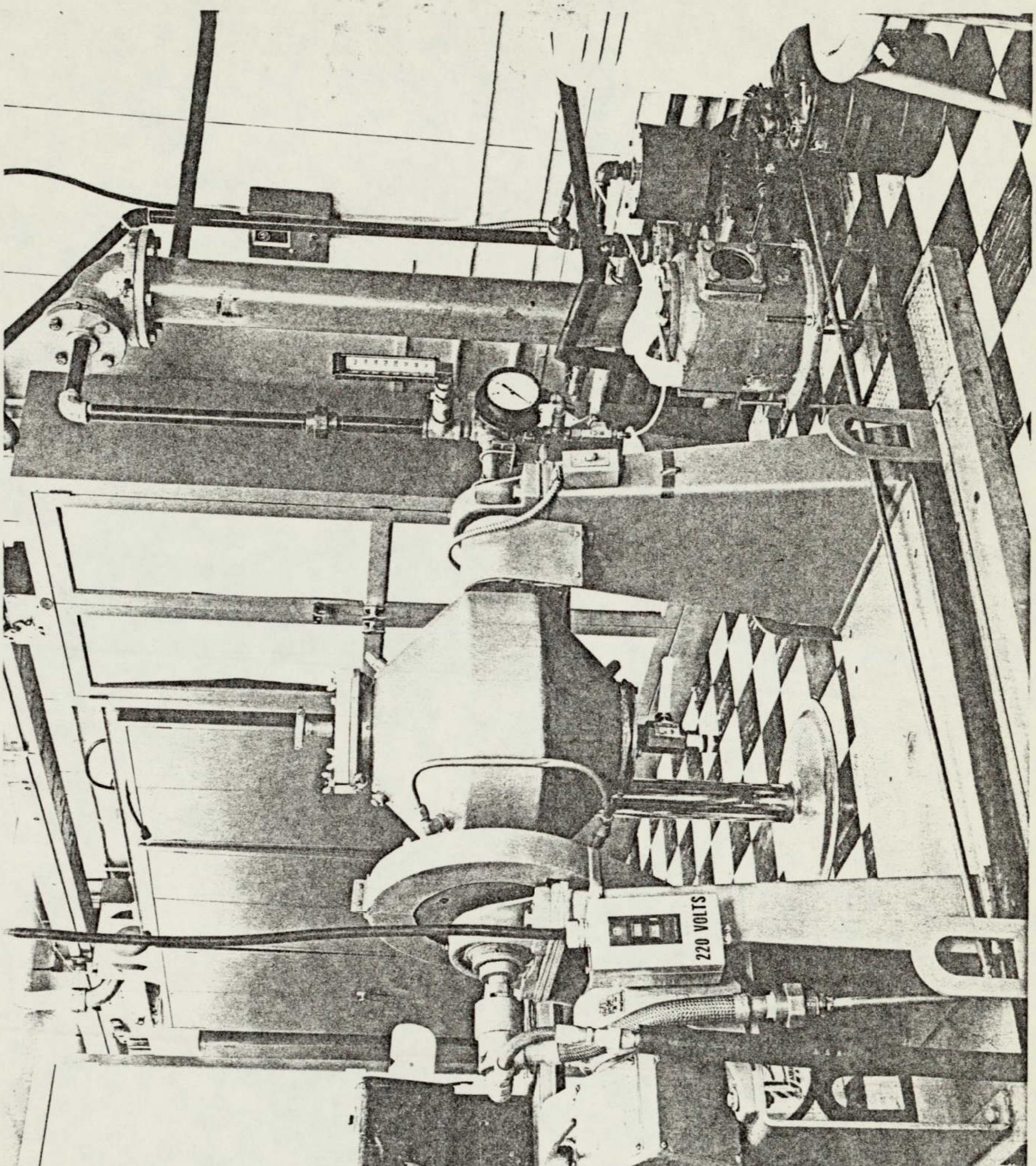


Figure 1
ROTARY VACUUM DRYER SETUP

MODULE VIBRATION

The objective of this task is to determine the effect of vibration on the HS-C sorbent material when packaged in the aluminum foam. The four-year-old HS-C material was used for all vibration testing.

The test fixture, designed to represent the canister configuration, can be seen in the photograph of Figure 2. The module was filled with 0.95 lbs. of HS-C material with no preload and the flow ΔP across the bed was measured.

The Shuttle qualification vibration requirement was simulated for the HS-C non-flight module. The module was subjected to this vibration loading for 48 minutes on each axis (as seen in Figure 3). The actual data curves for vibration testing are included in Appendix A, Test Data.

Upon completion of the vibration test, the flow ΔP across the bed was again measured. The results, tabulated in Table I, show that the post vibration readings were lower as noted. The fill port cap was then removed; the HS-C level did not appear to have settled. When the top plate was disassembled from the module, the aluminum foam was filled with the HS-C beads, as evident in Figure 2. The beads appeared spherical; no powdering was noted when the bed was inspected or when the bed was purged with nitrogen gas.

The bed was emptied and refilled with HS-C, approximately .93 lbs. of sorbent. The bed was packed with preload to simulate the prototype canister configuration. The ΔP and vibration tests were repeated with the preload bed. During the post test inspection, it was noted that the level of HS-C in the fill port had dropped approximately 1.45 inches. The ΔP test results for the preloaded bed, listed in Table I, show no change in the pre- and post- vibration measurements. The HS-C beads displayed no evidence of damage or powdering.

The HS-C beads from both the no preload bed and the preloaded bed were examined with a 200X microscope. No damage was evident. The beads that had been subjected to Shuttle vibration loads were also compared to HS-C beads from the same fabrication batch; the beads were identical in appearance. It is therefore concluded that the HS-C material can withstand vibration loading with the sorbent packaged in the aluminum foam. Bed preload does not appear to influence this characteristic, and test results indicate that preload can probably be eliminated from the canister design. However, a program to develop a bed filling technique should be initiated to confirm that the bed preload is not required.

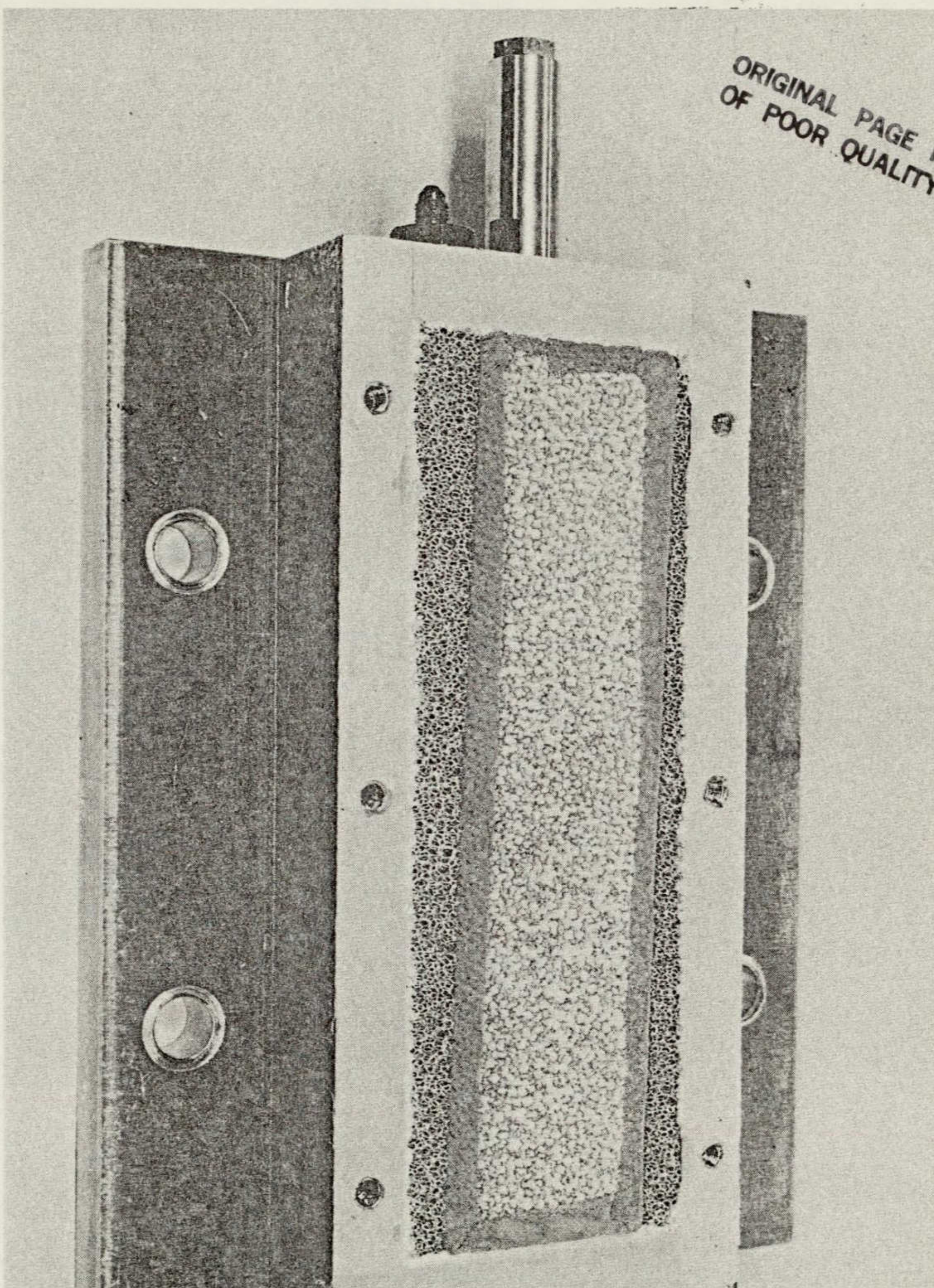
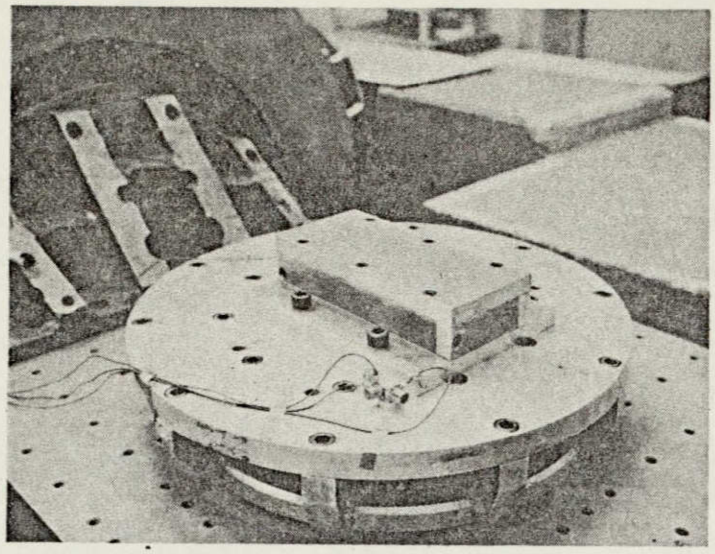
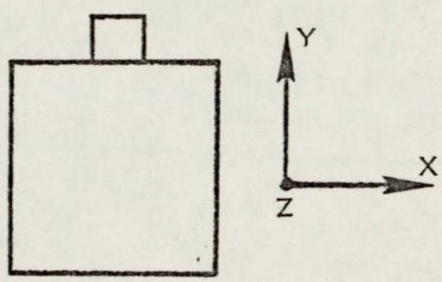


FIGURE 2
VIBRATION MODULE





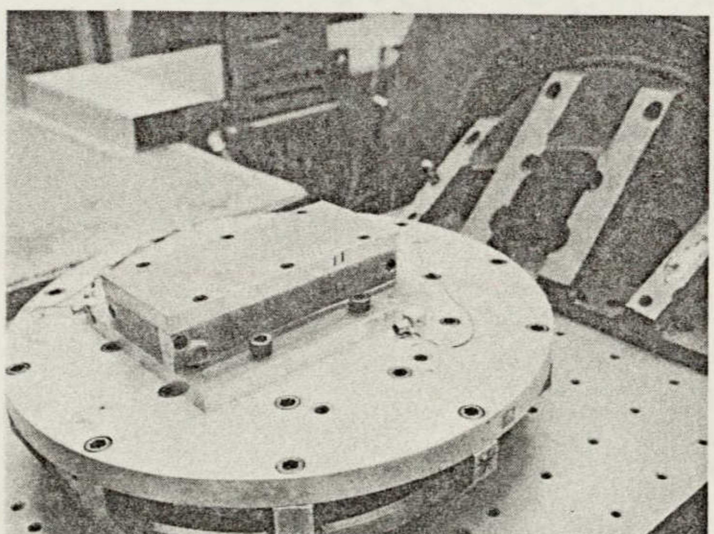


FIGURE 3

MODULE VIBRATION TEST SETUP

TABLE I

BED ΔP MEASUREMENTS

NO PRELOAD BED

FLOWMETER SCALE READING	ΔP (in. H_2O) PRE-VIBRATION	POST-VIBRATION
30	3.5	2.5
35	4.6	3.2
40	5.9	4.1

PRELOAD BED

FLOWMETER SCALE READING	ΔP (in. H_2O) PRE-VIBRATION	POST-VIBRATION
30	3.1	3.1
35	3.9	3.85
40	4.9	4.8

DESIGN CONCEPTS

The objective of this task was to define the flight concept for each major auxiliary component of the HS-C system in sufficient detail to determine if the component must be a new design or is an available flight unit. The design specifications were reviewed and a vendor search initiated to ascertain if the requirements could be satisfied by available flight qualified or Aircraft hardware The auxiliary components being reviewed were the process flow fan, emergency shutoff valve, bypass valve, pressure equilization valve, controller, and ullage-save compressor. The specifications for these components are listed in Appendix B of the Final Report, SVHSER 7182. The results of this effort are summarized in the revised prototype schematic, shown in Figure 4, and tabulated in Table 2, Auxiliary Components.

Requirements for the process flow fan are defined in the specification SVSKDR91798. The IMU fan, SV767350, Item 225, currently used in the Shuttle atmosphere revitalization subsystem (ARS) was selected for the HS-C system. Two IMU fans will be required for the operating range. With both fans operating, the 50 cfm airflow for the seven man case will be produced. With the fan operating and the airflow regulated by the bypass valve, the 30 cfm airflow for the four man case will be obtained. This will offer a power advantage; the system studies used 95 watts for the process fan. One IMU fan will require 43 watts, two fans require 79 watts. Integrating the two fans into the HS-C system will require two check valves SV766402-1; these Shuttle qualified valves are currently used in the IMU assembly, SV767400.

The emergency shut-off valve would be used to isolate the cabin air loop when a leak to vacuum is suspected. The valve must therefore be electrically activated with a manual override and automatically closes when a leak is detected. The emergency shutoff valve selected is a 3" ID Carleton Controls butterfly valve P/N 2371-001 qualified for vacuum exposure on the Skylab program as a molecular sieve isolation valve. This valve, currently made in a manually-operable version, will be modified to accept a General Design actuator, P/N 2535-3. This actuator is in production and is used in a cabin temperature control actuator/valve application for the Boeing 747 aircraft.

The bypass valve selected is manufactured by Carleton Controls as P/N 2814-0002, designed for the Experiment Vent Assembly for Dornier on the Spacelab. This 1.5 inch ID butterfly valve can be manually set for four positions. The valve position will be set for the crew size during the ground pre-flight servicing operations.

HS-C PROTOTYPE SYSTEM

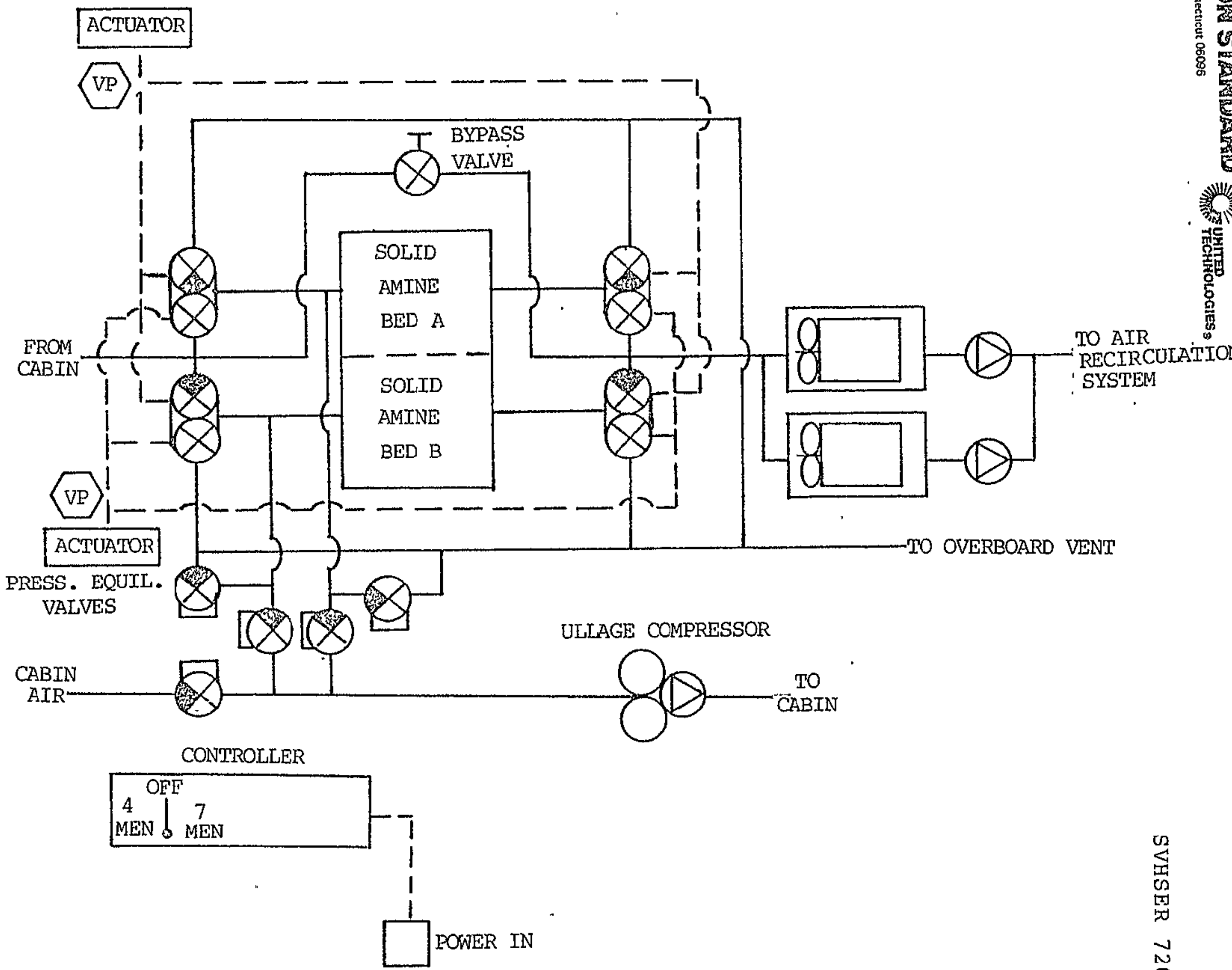


FIGURE 4
SYSTEM
SCHEMATIC

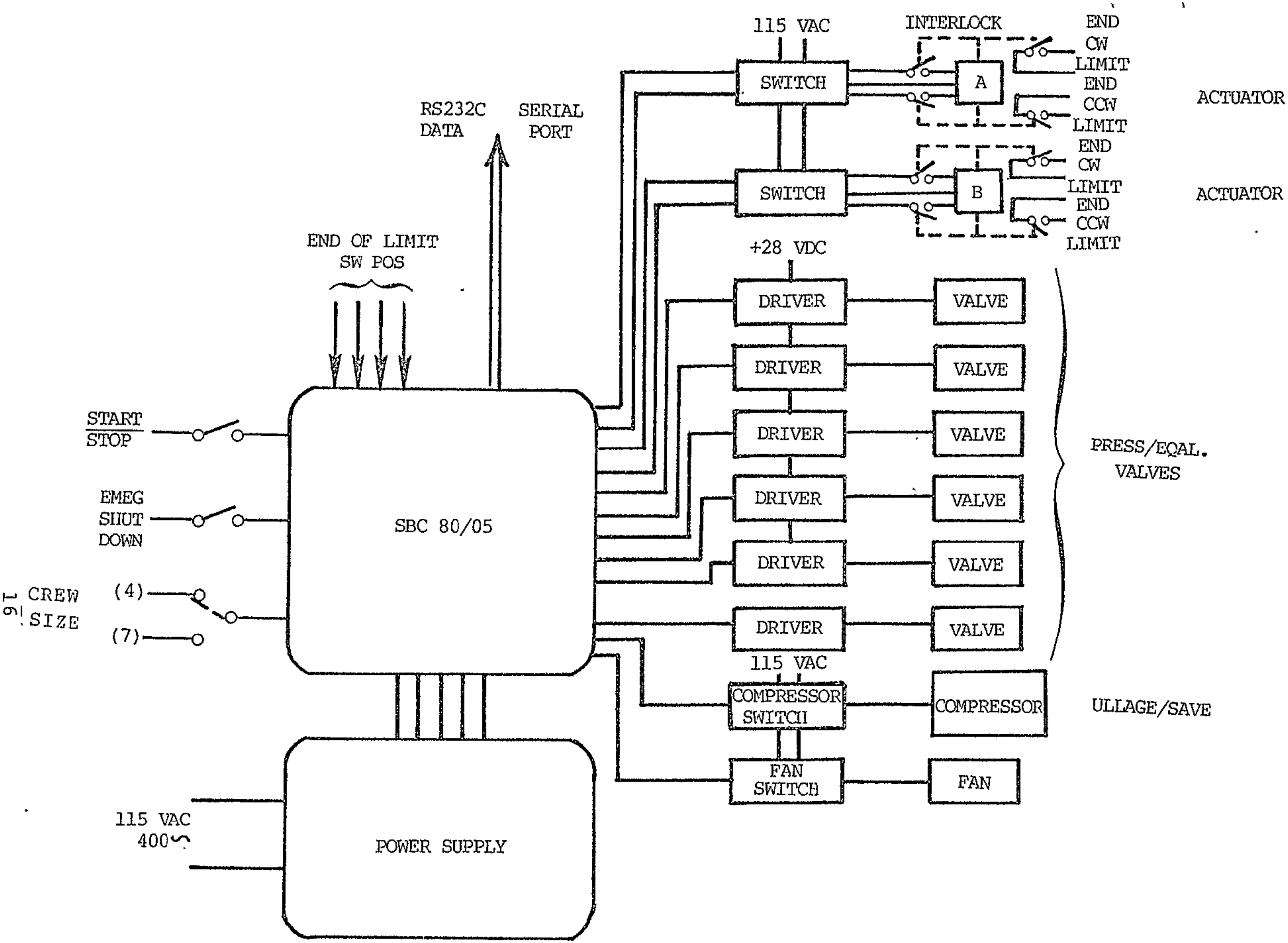
The pressure equilization valve proposed for the HS-C system is a direct acting solenoid valve manufactured by the Valcor Engineering Company as V70400-06. Six 3/4" valves will be incorporated into the HS-C system for the pressure equilization sequence during the bed switchover operation. The design offers a balanced poppet valve with viton seals which is suited for low pressure gas service. The construction is suitable for space flight service as all materials are compatible with space vacuum.

The electrical controller automatically times and sequences the vacuum valve actuators, the pressure equilization valves, and the ullage-save compressor and determines the operation of one or both process fans. The design and sequencing logic are therefore unique to the HS-C system and will be designed and manufactured by Hamilton Standard. The HS-C controller is a basic open loop sequencer system. Control is supplied via an Intel 8085 microprocessor. The actual sequence routines are stored in programmable, read-only memory. The input switch data is stored in read/write memory. System status is output via serial data circuits. Output power lines are switched by AC and DC solid state circuits. The programmable, read only memory also contains a monitor program. The monitor program scans the input switch positions and selects the appropriate sequence routine depending on the switch status. The monitor also formats the system status for serial data transmission on the RS232C serial data port. This port may be used for interfacing with an external data acquisition system. A hardware system provides an interlock for the actuators to prevent movement beyond the end limits. The controller block diagram is shown in Figure 5.

The ullage-save compressor's function is to retrieve as much of the adsorption bed cabin air as possible before the vacuum valve cycles the adsorption bed to the desorption mode, thus minimizing the loss of the trapped cabin air overboard to space. The ullage-save compressor must have the capacity to pump a .0538 m^3 (1.9 ft^3) volume from 103 KPa (14.9 psia) to below 13.7 KPa (2.0psia) in 1.7 minutes.

A vendor search was initiated for a compressor satisfying these criteria. No available unit was found and the companies contacted were not interested in developing a unit for such a limited production potential. Hamilton Standard prepared a preliminary compressor design concept, SVL-13920, shown in Figure 6, and is proposing to develop the flight concept model in-house. The design is a sliding vane rotary compressor using carbon vanes to eliminate lubrication.

Alternate methods for optimizing the HS-C operation have also been identified. These include automatic bypass flow control, selective fan operation, and variable cycle length. A study to evaluate these options should be undertaken to optimize the HS-C system for Shuttle.



HS-C CONTROLLER
BLOCK DIAGRAM
FIGURE 5

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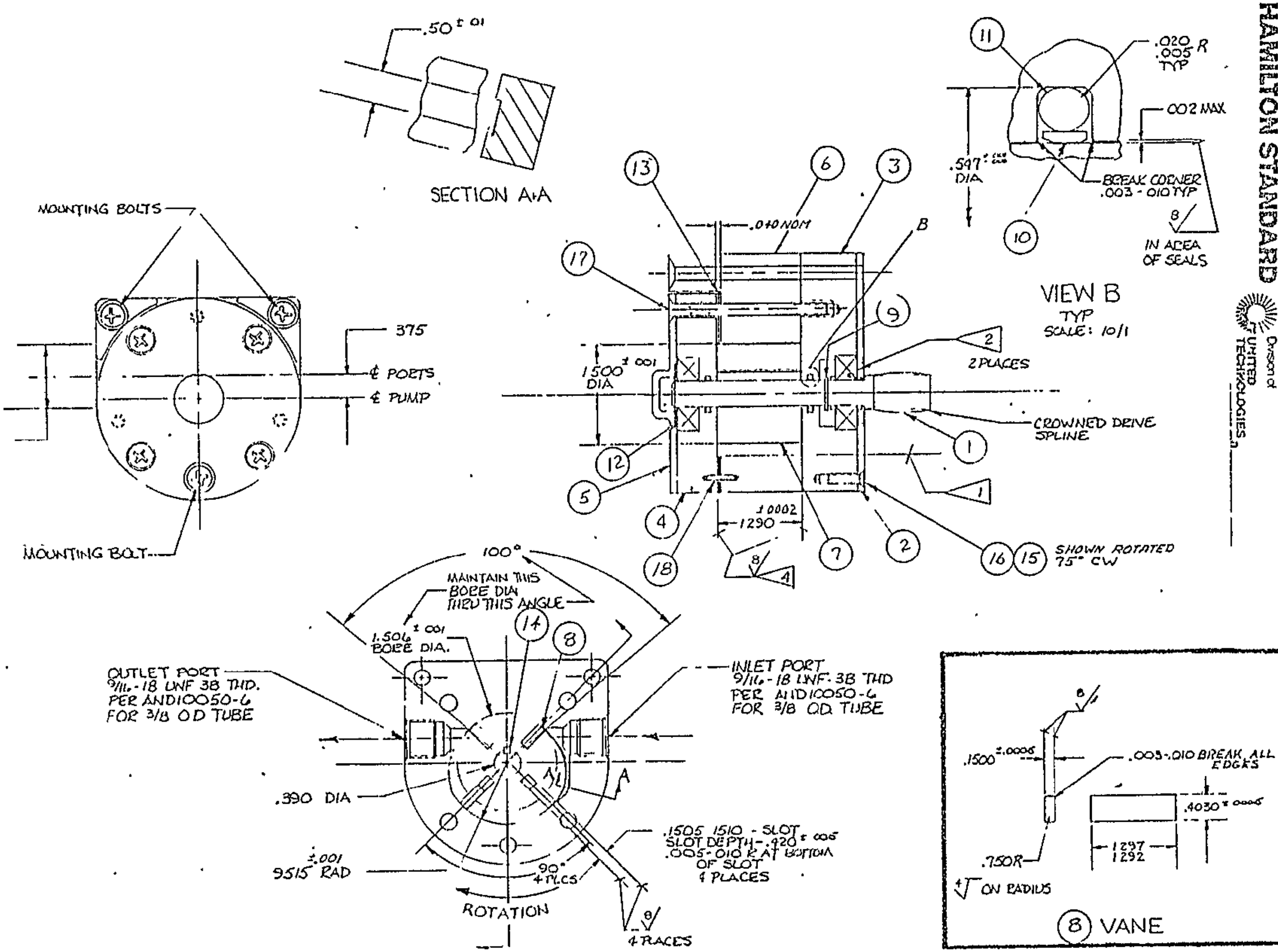

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SVL-13920

FIGURE 6
HS-C COMPRESSOR 4 SCFM

TABLE 2

AUXILIARY COMPONENTS

COMPONENT	Quantity	Source	Vendor P/N
Pressure Equilization Valve	6	Valcor Engineering Corporation	V70400-06
Bypass Valve	1	Carleton Controls Corporation	2814-0001 Modified
Process Fan	1	Shuttle IMU Fan Item 225	SV767350-2
	1	Shuttle Check Valve Item 217	SV766402-1
Controller	1	Hamilton Standard	N/A
Emergency Shutoff Valve	1	Carleton Controls Corporation	2371-001 Modified for General Design Actuator P/N 2535-3
Ullage-Save Compressor	1	Hamilton Standard	N/A

SYSTEM PERFORMANCE TESTING

The purpose of the flight prototype system testing was to verify system performance when the system was filled with 4-year-old HS-C material. The testing was also repeated with the newly fabricated HS-C in order to demonstrate that the batch process was duplicated with consistent results, and to establish a performance baseline for new material. The previous batch of HS-C, fabricated in 1974, was tested two years later in the breadboard canister and at three years of age was tested in the full-size prototype system.

System Test Setup

The completed and integrated test setup is shown schematically in Figure 7. The test setup was identical to that used for testing the prototype system previously.

Air from the simulated Shuttle volume (facility antichambers of Figure 8) is ducted to Rig 88 where it is first sampled for CO_2 partial pressure and dew point. The air then passes through a blower which provides part of the head for the plumbing loop. The air passes through a series of heat exchangers and electric reheaters which provide the temperature conditioning of the air. The air next passes through an annubar/manometer and valve arrangement which measures and controls flowrate.

The air is then plumbed to the prototype system where it passes through the adsorbing bed and is returned to the simulated Shuttle volume. The prototype system is shown in the test setup in Figure 9.

The metabolic CO_2 feed gas is introduced into the airstream in the return duct between the system and the simulated Shuttle volume. The CO_2 flow is regulated by a needle valve and flow rater. The feed rate is accurately measured by time averaging the decreasing weight of the high pressure CO_2 storage bottle.

The metabolic water feed system injects steam directly into the simulated Shuttle volume. The feed rate is controlled by a calibrated micro-metering valve mounted on the outlet of the constant water volume steam generator. Water flow to the steam generator is measured by time averaging the weight of a separate water storage tank. The storage tank is not plumbed to a water supply but is batch filled with triple distilled water.

The inside of the simulated Shuttle volume is arranged to guarantee adequate mixing of air. Return air from the prototype system, rich in CO_2, exhausts at one side of the chamber near the steam injection flow. A fan is used to mix the steam and return air with the chamber air. The air intake to the prototype system is located at the opposite side of the chamber so that it draws the mixed air. It is the CO_2 and humidity levels of this intake air that are used as the primary measurements of HS-C performance.

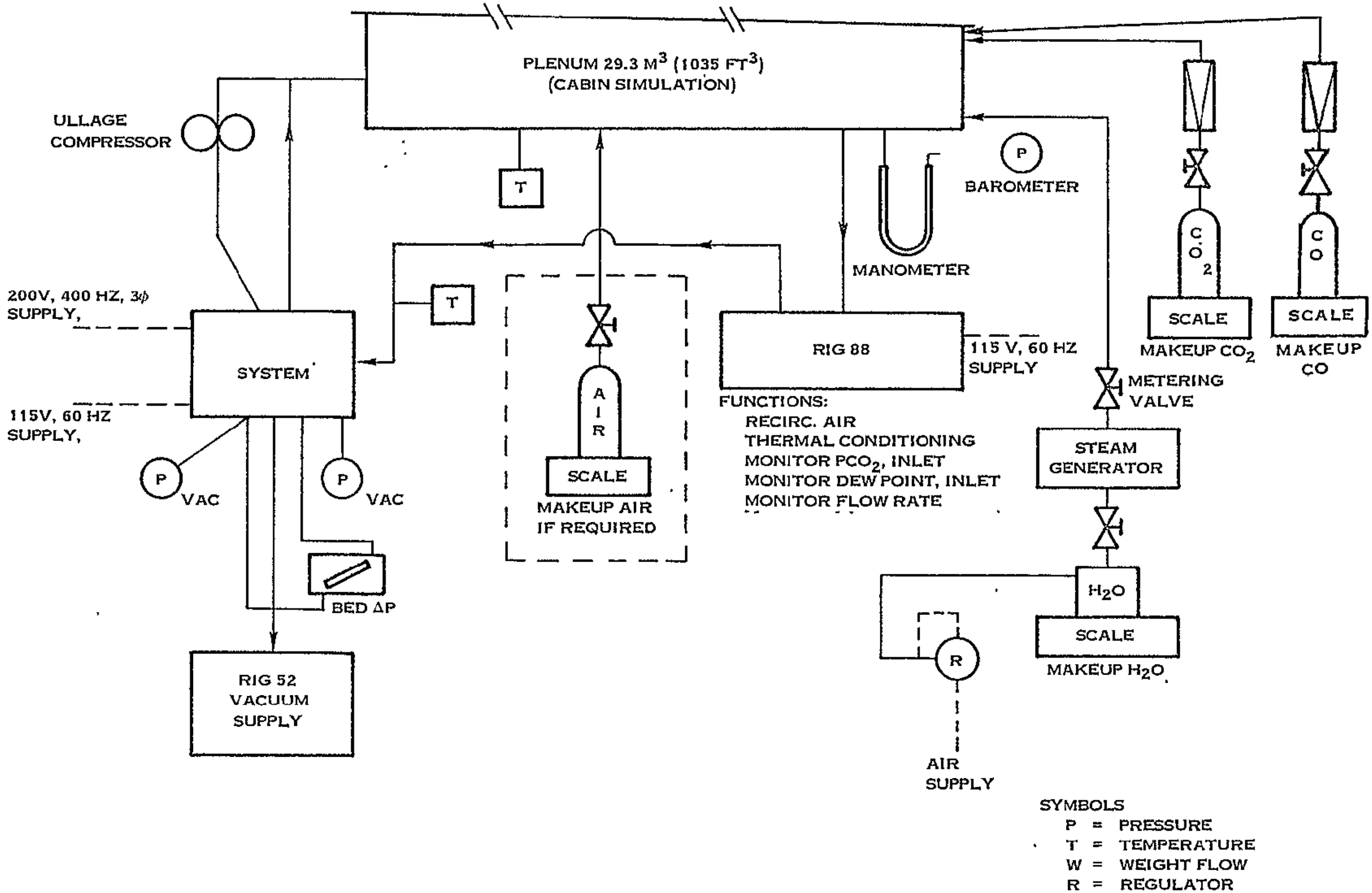

FIGURE 7
PROTOTYPE SYSTEM TEST SETUP

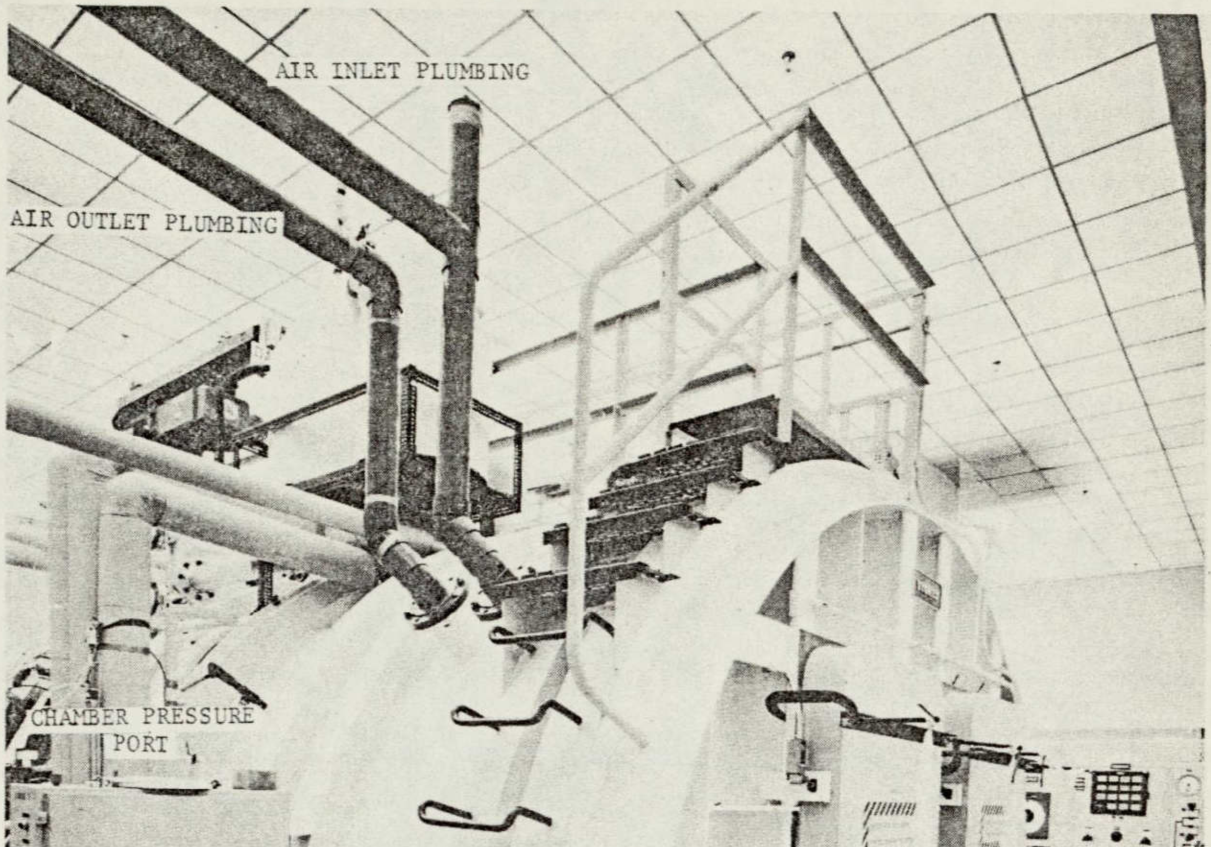

FIGURE 8

ANTICHAMBERS (USED AS SIMULATED SHUTTLE CABIN)

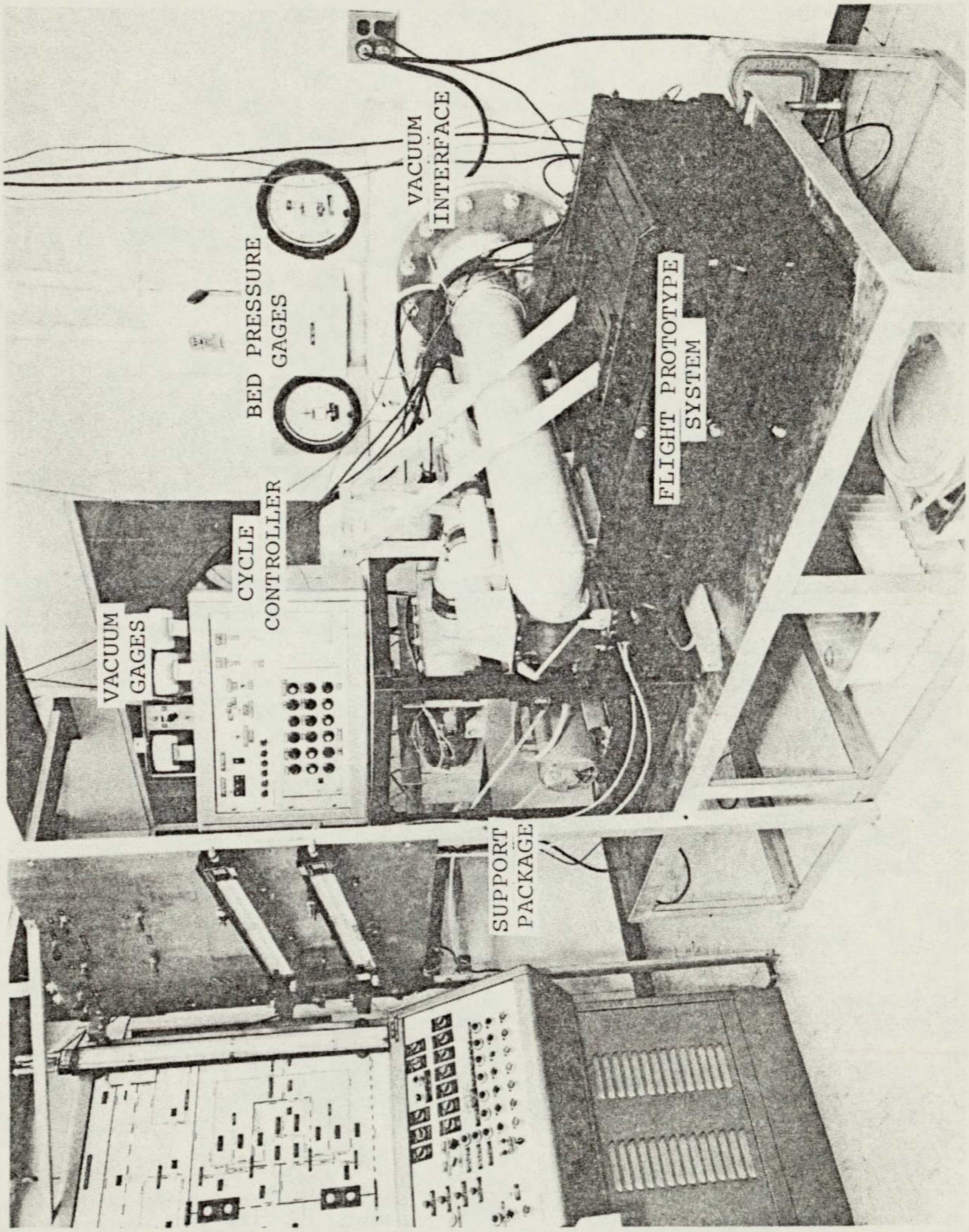

FIGURE 9
FLIGHT PROTOTYPE SYSTEM TEST SETUP

Rig 52 provides the vacuum supply for HS-C desorption. Rig 52 includes two parallel LN_2 cold traps which freeze CO_2 and water. In addition, the rig has three separate stages of vacuum pumps and blowers capable of 1.4 m^3/s (3,000 cfm) flow at 6.7 Pa (50 microns) inlet vacuum.

The parameters to be measured during testing were defined in the test setup schematic of Figure 9. The specific instruments used in each location are defined in Table 3.

System Testing

The Plan of Test was divided into six major test areas:

- .Leakage and Instrument Calibration
- .System and Bypass Flow Calibration
- .System Performance of 1974 Material
- .Leakage and Instrument Calibration
- .System and Bypass Flow Calibration
- .System Performance of 1978 Material

The Plan of Test is presented in Appendix B.

In addition to the testing defined in the Test Plan, the system was extensively tested parametrically under in-house funding in order to extend the data base. Vacuum desorption testing and single bed testing were also performed. The actual test sequence was:

- .Leakage and Instrument Calibration
- .System and Bypass Flow Calibration
- .System Performance of 1974 Material
- .Vacuum Desorption Test
- .Performance Mapping
- .Leakage and Instrument Calibration
- .System and Bypass Flow Calibration
- .System Performance of 1978 Material
- .Single Bed Operation

Each test is presented in detail in the following subsections.

Leakage and Instrument Calibration

The objective of this test series is to verify that all elements of system leakage are understood and accounted for during testing and that all instruments are calibrated within acceptable accuracies.

This test series involved four specific test areas as follows:

- .Vacuum System Leakage
- .Air System Leakage
- .CO_2 and H_2O Permeation
- .Instrument Calibration

TABLE 3

DATA REQUIREMENTS AND INSTRUMENTATION LIST

Parameter	Units	Accuracy	Instrument	Range and Units	Note
Rig 88 and HS-C Flow	cfm	± 10%	Annubar Manometer	0 to 30 in H_2O	
Rig 88 Outlet Temperature	°F	± 2°	Thermocouple	20 to 150°F	
Makeup CO_2 Flow	lb/hr	± 2% Full Scale	Flowrater	0 to 1.2 lb/hr	
Makeup H_2O Flow	lb/hr	± 5%	Metering Valve	0 to 3.3 lbm/hr	
HS-C Inlet Temperature	°F	± 2°	Thermocouple	20 to 150°F	
HS-C System Cycle Time	minutes	± 1% Cycle	Stop Clock	0 to 60	
HS-C System Vacuum		± 5% Non-Linear Scale	Hastings Gage and Pickup or Equivalent	0 to Atmos	
HS-C Bed Press. Delta	in H_2O	± 0.05	U-Tube Manometer	0 to 20 inches	
Plenum Temperature	°F	± 2°	Thermocouple	20 to 150°F	
Plenum Dew Point	°F	± 2°	Hygrometer	-40 to 120°F	Indigenous to Rig 88
Plenum PCO_2	mmHg	± 2% Full Scale	Infra-Red Analyzer	0 to 100% (100% = 7.6 mmHg)	Indigenous to Rig 88
Plenum CO Level	ppm	± 1% Full Scale	Ecolyzer	0-50 ppm	
Plenum/Ambient Press. Delta	in H_2O	± 0.2	U-Tube Manometer	0 to 30 inches	Indigenous to Rig 88
Weight Makeup Air	lbm	± 0.02	Scale	0 to 300 lb	
Weight Makeup CO_2	lbm	± 0.02	Scale	0 to 300 lb	
Weight Makup H_2O	lbm	± 0 02	Scale	0 to 300 lb	
Ambient Pressure	in. Hg	± 0.05	Barometer		
Ambient Temperature	°F	± 2°	Thermometer	20 to 400°F	

Vacuum System Leakage

The purpose of this test was to insure that the leakage of the vacuum portion of the flight prototype system, including the canister and vacuum valves, was sufficiently below the vacuum pumping rate to allow desorption of the HS-C beds.

A pressure decay test was conducted on each bed separately. The tests were run with each isolated volume being pumped down to a 100.6 kPa (14.6 psi) negative pressure. The vacuum system was operating to assure proper seating of the poppet valves. The leakage is calculated from the ideal gas formula:

$$\text{Leakage} = \frac{\text{Delta M}}{\text{Time}} = \frac{V}{RT}\ \frac{\text{Delta P}}{\text{Time}}$$

The resultant leakage is factored according to the full pressure differential experienced in actual testing. The prototype system was evaluated before performance testing on May 1, 1978. Bed A leakage was .105 cm^3/s(.0010 lb/hr) while that of Bed B was measured at .566 cm^3/s(.0054 lb/hr). The system leakage was well within the limit of 1.05 cm^3/s(.01 lb/hr).

The vacuum leakage test was repeated on October 13, 1978 after the system was filled with the 1978 HS-C batch and reinstalled on the test setup. Bed leakage was an acceptable 0.042 cm^3/s (.0004 lb/hr) for Bed A and 0.34 cm^3/s (.0032 lb/hr) for Bed B.

Air System Leakage

The purpose of this test was to establish the leakage rate of the overall air circuit which included the flight prototype system air circuit, Rig 88, the Shuttle simulated cabin volume chamber, and all interconnecting plumbing. The air system, excluding the canister assembly, was pressurized to 2.49 KPa (10 in. H_2O) and the pressure decay recorded at 389 g/hr (.856 lb/hr). This leakage rate was acceptable since the net effect on the CO_2 performance rates was 1% and on H_2O performance rates was 0.6%. This is within the accuracy of the instrumentation.

The leakage test of the air system was repeated after the prototype system was filled with the newly fabricated HS-C material and reinstalled into the test setup. The leakage was 0.5 kg/hr (1.09 lb/hr) which does not significantly affect the operational performance of the system. The imbalance between the CO_2 and H_2O feed rates and removal rates is corrected for the largest leakage value by increasing the feed rates by 1% or reducing the performance rates by 1%. This value is within the accuracy of the instrumentation and was therefore considered insignificant.

Instrument Calibration

The purpose of this calibration was to verify test measurements by demonstrating calibration before and after data collection.

All instrumentation was calibrated prior to testing by the Instrumentation and Metrology Department. All instruments were recalibrated as required by accepted standards during the test period. In addition, the CO_2 analyzers, dew pointers, and vacuum pressure instruments received special attention because of the critical nature of their readings. The Infra-Red CO_2 Analyzers (Liras) were calibrated each morning and before any detailed data collection period. The hygrometer (dew pointer) was balanced (null check) each morning and before any detailed data collection period.

System and Bypass Flow Calibration

The purpose of this test was to establish air flow through the HS-C bed and thus bypass flow as a function of pressure drop across the bed.

The airflow was increased in eight increments from 0 to 0.031 m^3/s (0 to 65 cfm). The airflow was then decreased in the same increments to measure any hysteresis in the instrumentation. A slight hysteresis was encountered, and the data was averaged to produce the curves in Figures 10 and 11.

The flow profile for Beds A and B for the 1974 batch of HS-C was approximately the same as that measured during previous testing. The pressure drop recorded for the newly-fabricated (1978) batch of HS-C was similar to the previous profile but was slightly higher at the higher flows, as evident in Figures 10 and 11.

System Performance

The purpose of this test was to establish the baseline performance of the HS-C prototype system when filled with HS-C material fabricated four years ago. The test was also repeated for the system filled with the newly fabricated HS-C material. This test would then demonstrate system performance with the new sorbent, and verify the repeatability of the HS-C fabrication process.

System performance testing with the four year old HS-C material was initiated on May 10, 1978 per the Plan of Test, summarized in Table 4. Three environments were tested; namely, the 7 men at 80°F, 7 men at 65°F, and 4 men at 65°F cabin environments. Testing was accomplished in two ways: the parameteric test mode and the mission test mode. The parameteric test mode controlled a specific dewpoint and CO_2 partial pressure by changing the CO_2 and water feed rates. In the mission test mode, the four man metabolic rates for CO_2 and water were fed into the test loop and the HS-C system established the equilibrium CO_2 partial pressure and dewpoint.

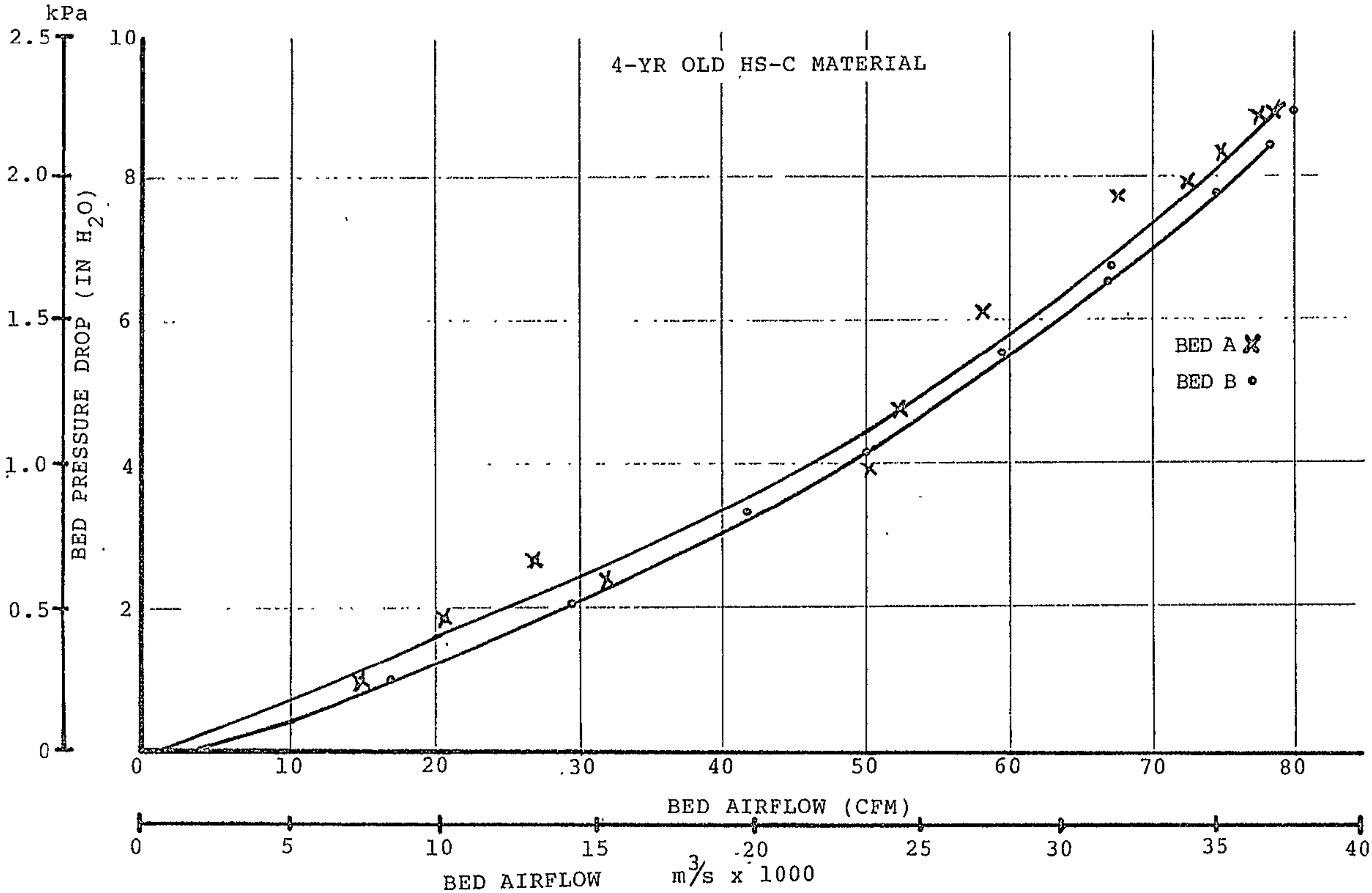

FIGURE 10
CANISTER FLOW CHARACTERISTICS

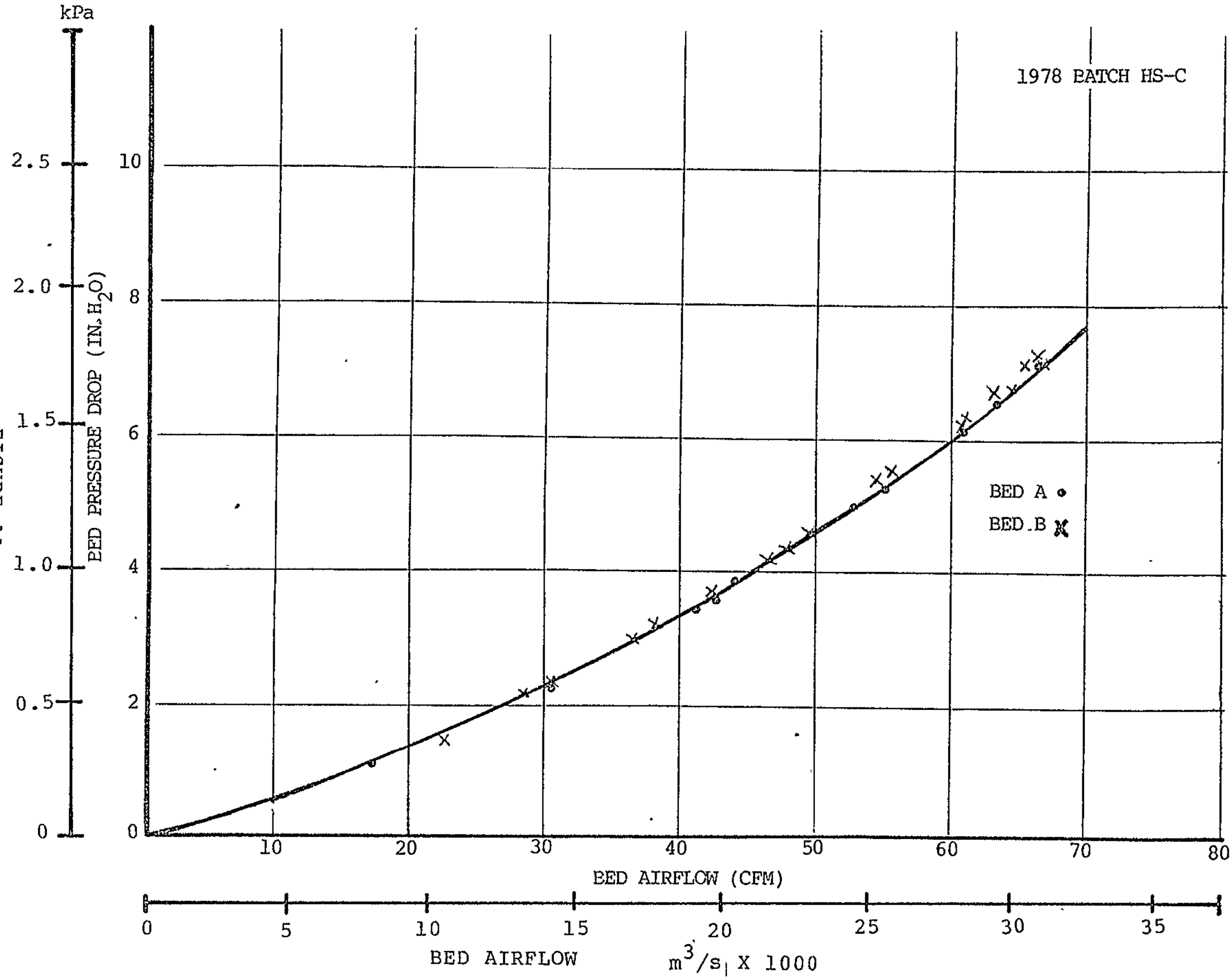

FIGURE 11
CANISTER FLOW CHARACTERISTICS

TABLE 4

PLAN OF TEST

Test No.	Environment	Fixed Conditions	Test Variables	Test Mode	HS-C Material
1	7 Men, 80°F	80°F DB Temperature 50 cfm Air Flow 58-60°F Dew Point 18/18 Cycle 4.5 mmHg PCO_2	H_2O Feed Rate CO_2 Feed Rate	Parametric	4 Years Old
2	7 Men, 65°F	65°F DB Temperature 50 cfm Air Flow 38-40°F Dew Point 18/18 Cycle 7.0 mmHg PCO_2	H_2O Feed Rate CO_2 Feed Rate	Parametric	4 Years Old
3	7 Men, 80°F	80°F DB Temperature 50 cfm Air Flow 58-60°F Dew Point 18/18 Cycle 4.5 mmHg PCO_2	H_2O Feed Rate CO_2 Feed Rate	Parametric	New
4	7 Men, 65°F	65°F DB Temperature 50 cfm Air Flow 38-40°F Dew Point 18/18 Cycle 7.0 mmHg PCO_2	H_2O Feed Rate CO_2 Feed Rate	Parametric	New
5	4 Men, 65°F	65°F DB Temperature 50 cfm Air Flow 40/40 Cycle .42 lb/hr CO_2 Feed Rate .78 lb/hr H_2O Feed Rate	PCO_2 Dew Point	Mission	New

Table 5 compares the performance of the HS-C material at three and four years of age. No significant degradation in performance was noted. The apparent 4% increase in CO_2 performance resulted from a correspondingly lower CO_2 feed rate. The test data for all contractual testing is summarized in Table 6.

The three test environments were repeated with the prototype system filled with the newly fabricated HS-C. The test results are tabulated in Table 5. With the 7 men at 80°F conditions, the system CO_2 performance was 13.1% better than that of the four year old material; water removal performance showed no significant improvement. The 7 men at 65°F environment testing demonstrated a 14.5% improved CO_2 performance and a 10.3% improved water performance. When the four man crew metabolic rates were fed into the test environment, the system maintained a much lower CO_2 partial pressure than that measured during testing with the four year old material (5.1 mmHg vs. 6.7 mmHg). It was therefore concluded that the HS-C fabrication process had been duplicated with acceptable results, and that the performance baseline was established for this material. The batch variation cannot be established conclusively until this batch is three years old (1981) since the 1974 batch was not tested in the prototype system until three years of age.

In studying the test summary results in Table 6, it is noted that tests 3, 4, and 5 were repeated. Initial results were questionable; a post test instrumentation check revealed a problem with the annubar used to set the air flow. The tests marked with an asterisk (*) were therefore performed with higher flows than desired. An orifice and manometer were added to the test loop and the three test conditions rerun. The verified data is that used for all performance comparisons.

During system testing of the 1978 HS-C material, both the inlet and outlet CO_2 partial pressure and the inlet dewpoint were recorded every 30 seconds for a few cycles for each bed. The resulting bed performance profiles are shown in Figure 12 and 13. As evident in the graphs, the profiles are identical; the performance is apparently not affected by the aging of the PEI-18 used in the material fabrication. Differences in the performance of the HS-C sorbent coated with new PEI-18 and the sorbent coated with four year old PEI-18 were not distinguishable.

TABLE 5
HS-C PERFORMANCE

TEST ENVIRONMENT	MATERIAL AGE		
	1978 BATCH	1974 BATCH	
		3 YEARS OLD	4 YEARS OLD
7 Men @ 80°F	.716 lb/hr CO_2 1.807 lb/hr H_2O	.618 lb/hr CO_2 1.72 lb/hr H_2O	.633 lb/hr CO_2 1.786 lb/hr H_2O
7 Men @ 65°F	.639 lb/hr CO_2 .938 lb/hr H_2O		.558 lb/hr CO_2 .850 lb/hr H_2O
4 Men @ 65°F	5.1 mmHg PCO_2 38.5°F Dew point	7.1 mmHg PCO_2 39.5°F Dew point	6.7 mmHg PCO_2 39°F Dew point

TABLE 6A
TEST SUMMARY
CONTRACTUAL TESTING
(SI UNITS)

TEST NO.	TOTAL TEST HOURS	TIME ON CONDITION (HR.)	TEMP (°C)	FLOW (m^3/s)	CYCLE TIME (MIN/MIN)	PCO_2 (KPA)	CO_2 FEED (KG/HR)	CO_2 NOM. METABOLIC RATE (MAN)	DEW POINT (°C)	H_2O FEED (KG/HR)	H_2O METABOLIC RATE (MAN)	MAT'L BATCH	TEST MODE
1	11.1	1.8	26.7	0.024	18/18	0.57	0.290	7.3	15.0	0.80		1974	PARAMETRIC
1	17.1	4.0	27.8	0.024	18/18	0.60	0.293	7.3	14.4	0.79			
1	22.2	5.1	26.7	0.024	18/18	0.60	0.309	7.2	14.7	0.78			
1	69.7	45.5	27.2	0.024	18/18	0.60	0.287	7.2	15.0	0.81			
2	69.7	--	18.3	0.024	18/18	0.60	--	--	3.9	--	--		
2	75.1	25.3	18.3	0.024	18/18	0.96	0.253	6.3	3.9	0.39			
2A	75.1	--	18.3	0.024	40/40	--	0.191	4.0	--	0.35	4.0		MISSION
2A	87.0	10.9	18.3	0.024	40/40	0.89	0.183	3.8	3.9	0.37	7.3		
3	0.	--	26.7	0.024	18/18	0.60	--		15.0			1978	PARAMETRIC
3	42.0	37.0	27.2	0.024	18/18	0.61	0.343	8.6	14.7	0.82	7.8		
3	54.5	9.5	26.7	0.024	18/18	0.64	0.340	8.5	14.4	0.88	8.3		
3	71.0	16.5	26.7	0.024	18/18	0.57	0.334	8.4	14.4	0.87	8.3		
4	157.5	61.3	18.9	*	18/18	0.95	0.331	8.3	5.0	0.49	--		
5	243.5	80.7	18.9	*	40/40	0.56	0.190	4.0	4.7	0.36	4.0		MISSION
5	258.8	14.9	16.7	0.024	40/40	0.68	0.198	4.2	3.6	0.36	4.0		
4	272.4	11.9	16.1	0.024	18/18	0.95	0.290	7.3	4.4	0.43			PARAMETRIC
3	315.2	42.0	27.2	0.024	18/18	0.59	0.325	8.1	15.3	0.82			

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TABLE 6 B

CONTRACTUAL TESTING SUMMARY

US UNITS

Test No.	Total Test Hours (Hr.)	Time On Condition (Hr.)	Temp. (°F)	Flow (CFM)	Cycle Time (min/min)	PCO_2 (mmHg)	CO_2 Feed (lb/hr)	CO_2 Nom. Metabolic Rate (Man)	Dew Point (°F)	H_2O Feed (°F)	H_2O Metabolic Rate (Man)	Mat'l Batch	Test Mode
1	11.1	1.8	80	50	18/18	4.3	.640	7.3	59	1.76	7.6	1974	Parametric
1	17.1	4.0	82	50	18/18	4.5	.646	7.3	58	1.745	7.6		
1	22.2	5.1	80	50	18/18	4.5	.632	7.2	58.5	1.72	7.5		
1	69.7	45.5	81	50	18/18	4.5	.633	7.2	59	1.786	7.8		
2	69.7	—	65	50	18/18	4.5	—	—	39	—	—		
2	75.1	25.5	65	50	18/18	7.2	.558	6.3	39	.850	4.4		
2A	75.1	—	65	50	40/40	—	.42	4.0	—	.78	4.0		Mission
2A	87.0	10.9	65	50	40/40	6.7	.404	3.8	39	.816	4.2		
3	0	—	80	50	18/18	4.5	—	—	59	—	—	1978	Parametric
3	42.0	37	81	50	18/18	4.6	.756	8.6	58.5	1.805	7.8		
3	54.5	9.5	80	50	18/18	4.8	.749	8.5	58	1.928	8.3		
3	71.0	16.5	80	50	18/18	4.3	.736	8.4	58	1.922	8.3		
4	157.5	61.3	66	*	18/18	7.1	.730	8.3	41	1.085	5.6		
5	243.5	80.7	66	*	40/40	4.2	.418	4.0	40.5	.789	4.0		Mission
5	258.8	14.9	62	50	40/40	5.1	.437	4.2	38.5	.784	4.0		
4	272.4	11.9	61	50	18/18	7.1	.639	7.3	40	.938			Parametric
3	315.2	42.0	81	50	18/18	4.4	.716	8.1	59.5	1.807	7.8		

* Flow Questionable

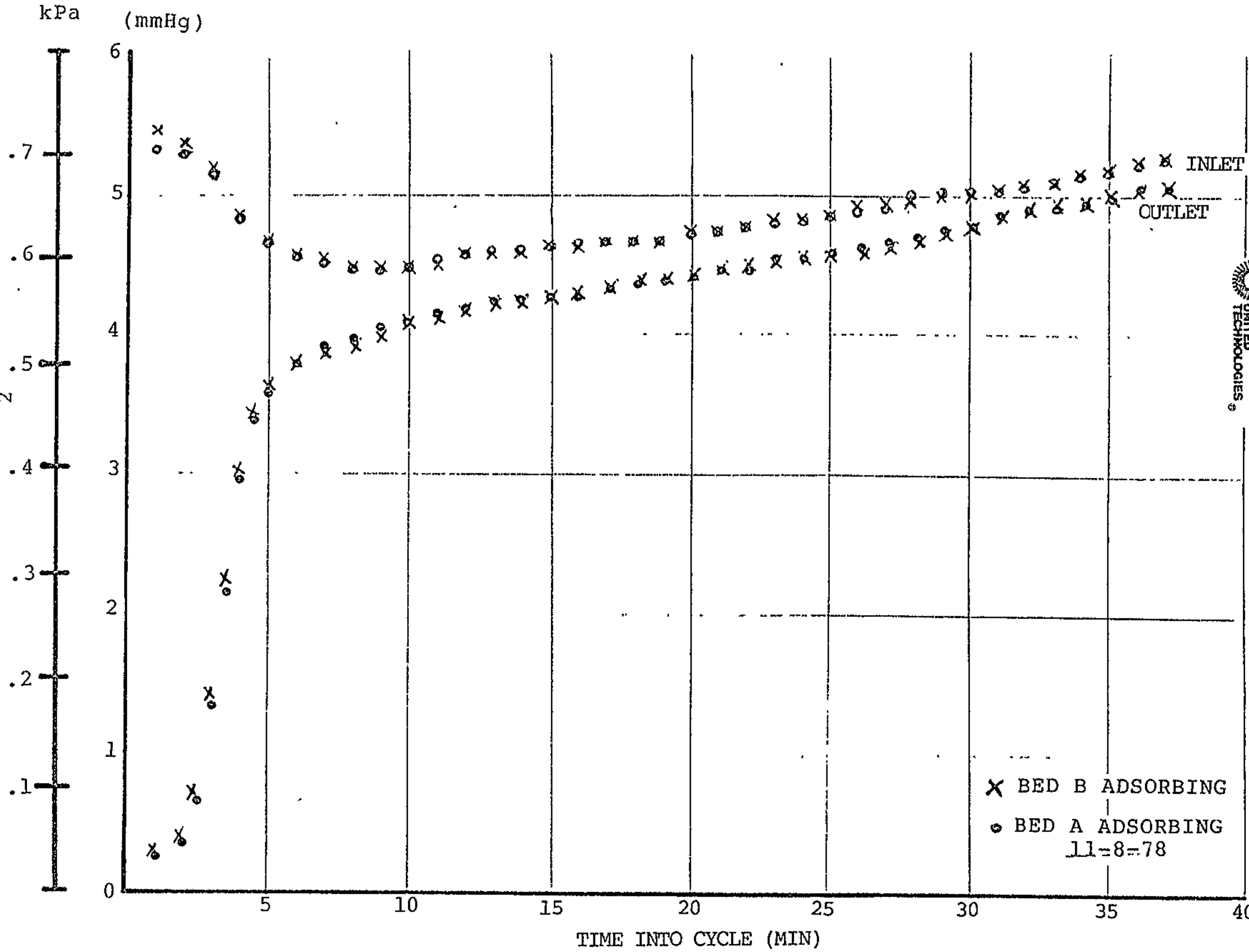

FIGURE 12
CO_2 PERFORMANCE PROFILE

SVHSER7208

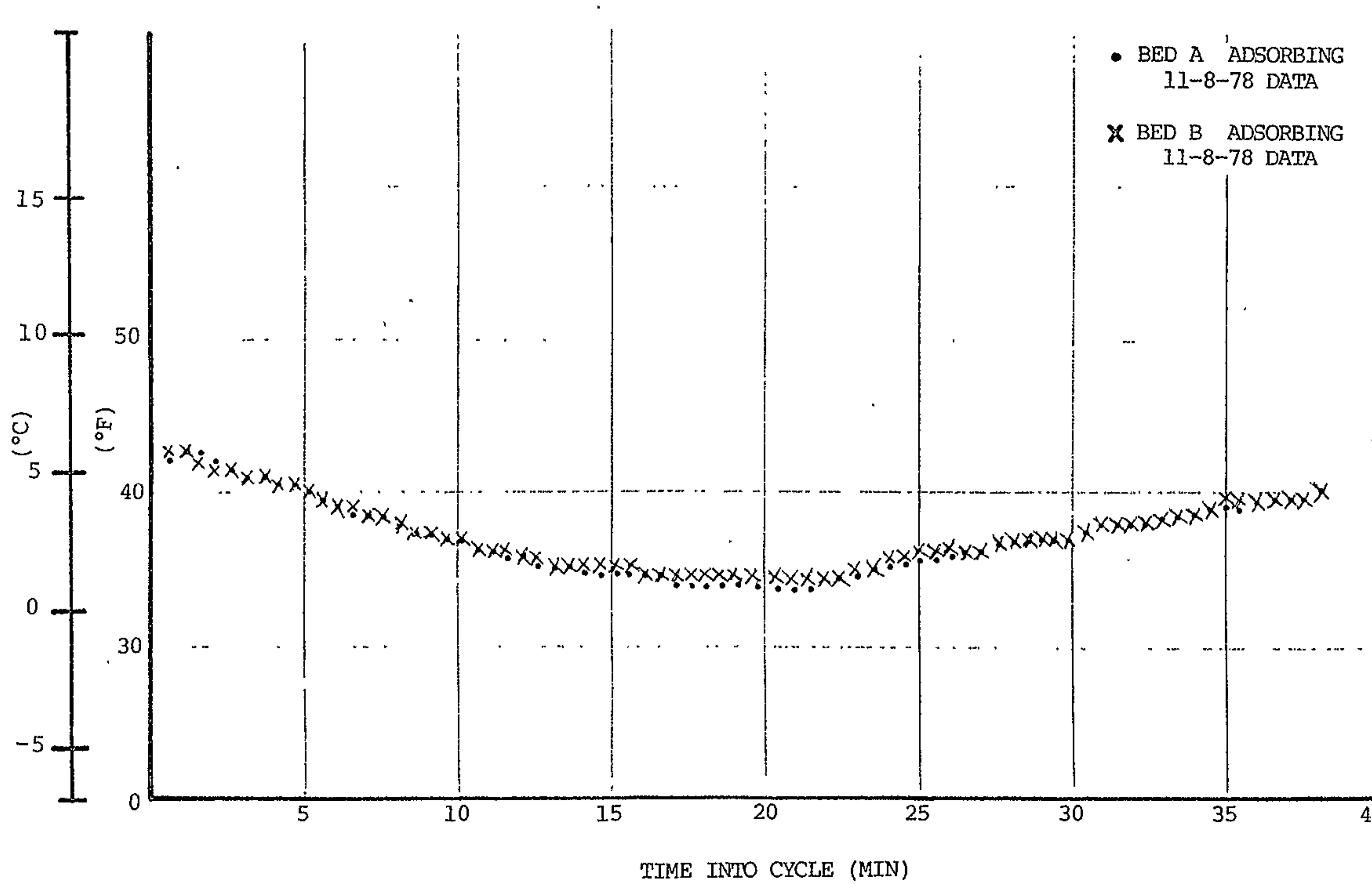

FIGURE 13
WATER PERFORMANCE PROFILE

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SVHSER7208

Vacuum Desorption Testing

The purpose of the vacuum desorption testing was to determine the effect of the vacuum desorption level on the system performance.

After establishing a performance baseline for the four-year-old material, the vacuum desorption level was changed by installing an orifice plate at the vacuum interface with Test Rig 52. The 7 men at 80°F environment was established for each test, and the CO_2 and water removal rates were determined. This data for the prototype system, together with the data from the breadboard system testing documented in the Interim Report, is shown in Figures 14 and 15. The actual data for the prototype system is tabulated in Table 7. Both the breadboard and prototype data indicate that the CO_2 adsorption linearly degrades with increasing desorption pressure. It is also evident that water capacity decreases more rapidly than CO_2 capacity at the higher desorption pressure. The data confirms that, from a design viewpoint, the system can operate with vacuum pressures greater than 0.26 KPa (2mmHg) if the bed size is proportionately larger. It should be noted that in Figure 15, a performance factor of 1.0 at the seven men at 80°F conditions (.633 lb/hr CO_2, 1.786 lb/hr H_2O) was selected.

The absolute pressure in the canister bed is shown as a function of time into the cycle in Figure 16.

Performance Mapping

The objective of this testing was to construct performance maps for the HS-C solid amine system based upon parametric test data. To achieve this objective, the parameters such as air flow, cycle time, dew point, and CO_2 partial pressure were varied to determine the effect on system performance. The prototype system using the four-year-old HS-C material was used for this test.

The test data is summarized in Table 7. The data was reduced and analyzed to construct the performance maps of Figures 17, 18, and 19, which show the CO_2 removal versus the airflow for a specific cycle time; namely, 10/10, 20/20, and 40/40 minute cycle times. From the performance maps it is possible to optimize an HS-C system design for bed weight, air flow, and cycle time for any CO_2 removal rate at CO_2 partial pressures from 1.0 to 7.6 mmHg. In addition, the analysis confirmed that the four-year-old material had undergone virtually no degradation in the last year (since the water save parametric testing).

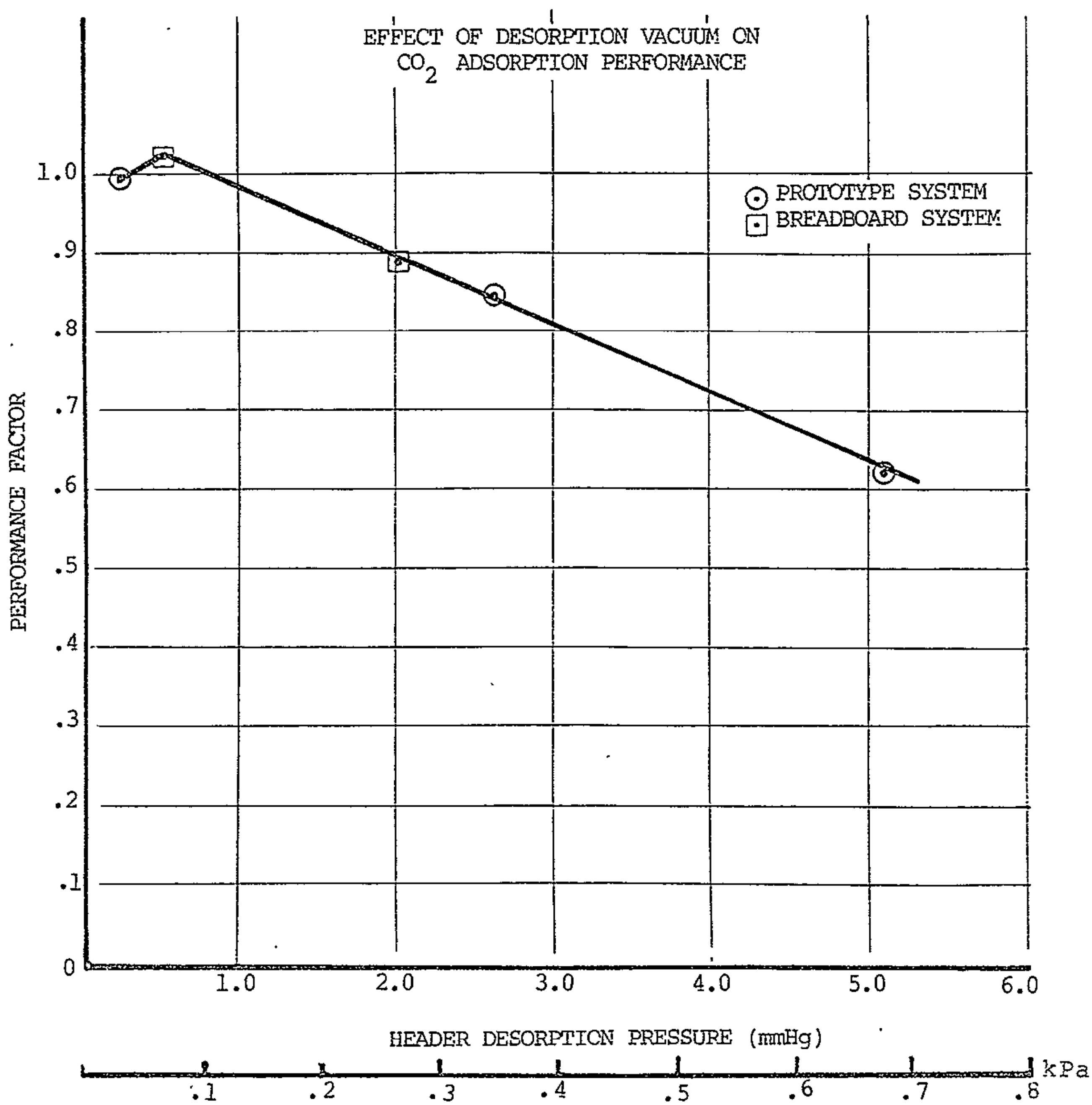


FIGURE 14

CO2 PERFORMANCE PROFILE

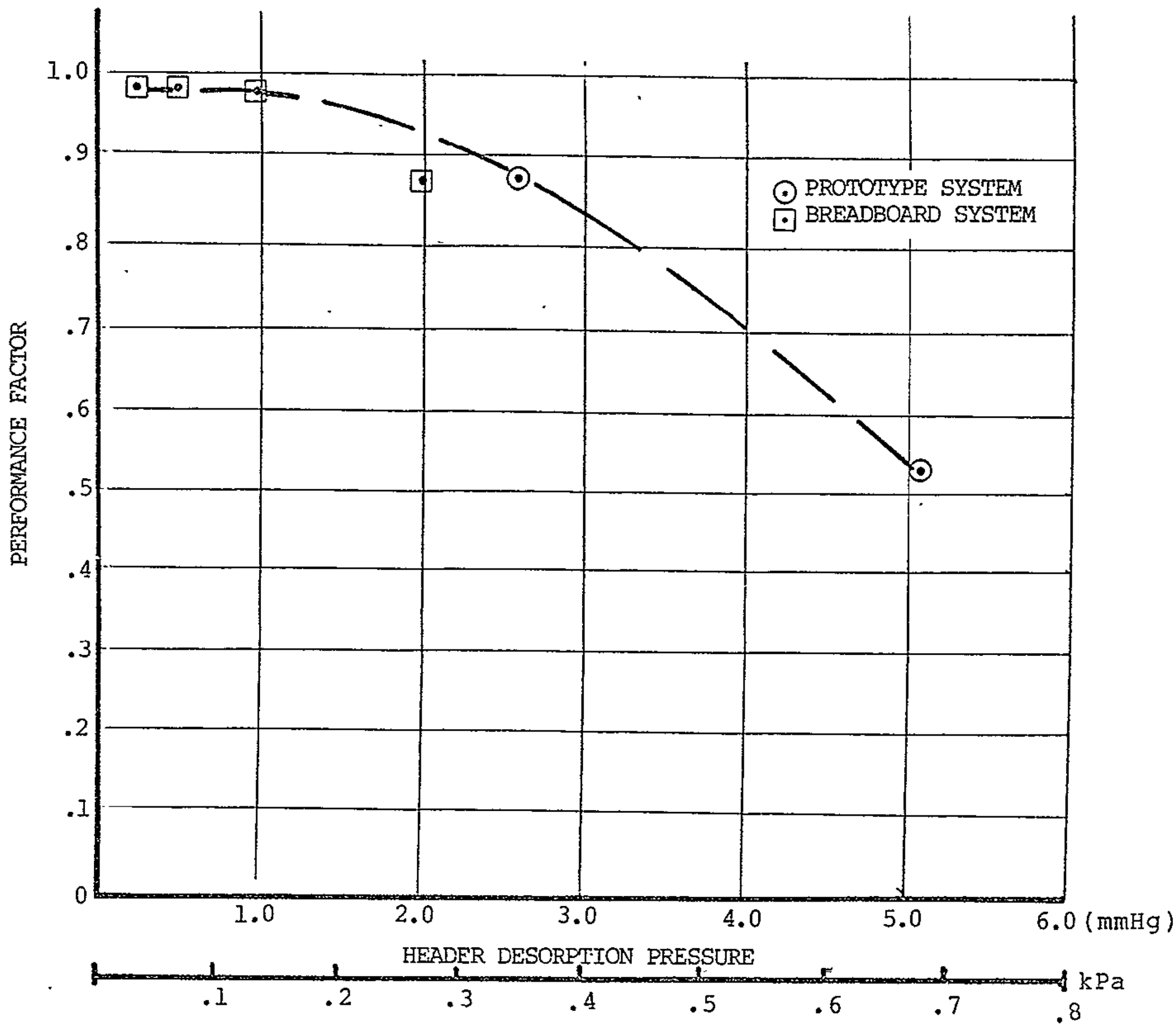


FIGURE 15.

WATER PERFORMANCE PROFILE

TABLE 7 A
PARAMETRIC TEST SUMMARY
(SI UNITS)

TEST	TOTAL TEST HOURS (HR.)	TIME ON CONDITION (HR)	TEMP. (°C)	FLOW (m^3/s)	CYCLE TIME (MIN/MIN)	PCO_2 (KPA)	CO_2 FEED (KG/HR)	DEW POINT (°C)	H_2O FEED (KG/HR)	MAT'L BATCH	COMMENTS
VACUUM DESORPTION	13.8	10.2	26.7	.024	18/18	0.56	.181	16.7	.43	1974	12.7mm ORIFICE
	27.9	9.5	26.1	.024	18/18	0.61	.249	11.7	.73		25.4mm ORIFICE
	42.3	13.4	26.1	.024	18/18	0.60	.247	15.0	.72		25.4mm ORIFICE
PARAMETRIC MAPPING	54.8	8.9	26.7	.033	19/19	0.43	.222	9.4	.67	1974	
	69.9	13.9	27.2	.033	19/19	0.40	.244	15.8	.98		
	83.6	9.7	20.6	.033	20/20	0.40	.240	15.3	1.29		
	97.1	7.5	26.7	.033	20/20	0.40	.264	15.6	1.06		
	111.5	14.4	27.2	.033	20/20	0.40	.277	15.3	1.05		
	125.3	12.6	20.6	.033	20/20	0.43	.231	8.9	0.76		
	137.3	7.0	20.6	.033	20/20	1.01	.323	8.9	0.81		
	146.1	8.0	20.6	.033	10/10	1.01	.364	8.9	0.59		
	159.4	9.3	20.6	.033	10/10	1.01	.363	9.4	0.75		
	169.0	8.6	20.6	.033	10/10	0.44	.263	8.9	0.71		CO_2 UNSTABLE
	183.9	14.3	20.6	.033	10/10	0.40	.268	8.9	0.70		
	196.5	9.1	20.0	.024	10/10	0.40	.255	8.9	0.61		
	210.7	12.0	21.1	.005	10/10	0.40	.108	8.3	0.09		
	224.4	9.7	21.1	.009	10/10	0.40	.173	8.3	0.18		
	238.5	13.1	20.6	.005	10/10	1.01	.240	8.3	0.11		
	252.5	12.0	20.6	.005	20/20	1.01	.187	8.3	0.12		
	265.8	9.9	20.6	.005	20/20	0.40	.114	8.3	0.18		
	277.1	11.3	20.6	.005	40/40	0.40	.086	8.1	0.14		
	292.1	9.3	20.6	.005	40/40	1.01	.144	8.3	0.12		
	306.3	8.3	26.7	.005	20/20	0.40	.099	8.3	0.12		
	320.4	10.4	25.6	.005	20/20	0.40	.110	15.8	0.21		
	335.4	10.2	21.1	.005	20/20	0.40	.117	8.9	0.16		
	349.5	10.7	21.1	.005	10/10	0.40	.105	8.9	0.11		
	362.1	8.0	22.2	.024	20/20	0.40	.186	8.3	0.51		
	389.1	10.1	21.1	.032	40/40	1.01	.213	7.8	0.53		
	402.8	9.2	21.1	.032	40/40	0.40	.164	7.8	0.49		
	410.0	4.0	22.2	.014	10/10	1.01	.325	8.3	0.30		
	414.0	3.0	22.2	.014	10/10	0.60	.275	8.3	0.30		
	432.6	3.5	22.2	.014	20/20	1.01	.271	8.3	0.36		
	438.1	5.5	22.2	.014	20/20	0.67	.210	8.3	0.34		
	450.3	5.0	22.2	.014	40/40	1.01	.191	8.3	0.34		
SINGLE BED OPERATION	16.2	2.7	21.1	.024	18/18	0.97	.142	8.1	0.32	1978	
	40.0	19.3	21.1	.024	18/18	0.99	.141	7.5	0.29		
	56.5	10.7	21.1	.024	10/10	1.00	.186	5.6	0.28		
	65.6	7.2	21.1	.014	10/10	0.96	.158	8.1	0.26		

TABLE 7B

PARAMETRIC TEST SUMMARY
(US UNITS)

TEST	TOTAL TEST HOURS (HR)	TIME ON CONDITION (HR)	TEMP (°F)	FLOW (CFM)	CYCLE TIME (MIN/MIN)	PCO_2 (mmHg)	CO_2 FEED (LB/HR)	DEW POINT (°F)	H_2O FEED (LB/HR)	MAT'L BATCH	COMMENTS
VACUUM DESORPTION	13.8	10.2	80	50	18/18	4.2	.399	62	.947	1974	1/2" ORIFICE
	27.9	9.5	79	50	18/18	4.6	.548	58	1.618		1" ORIFICE
	42.3	13.4	79	50	18/18	4.5	.544	59	1.594		1" ORIFICE
PARAMETRIC MAPPING	54.8	8.9	80	70	19/19	3.2	.490	49	1.487	1974	
	69.9	13.9	81	70	19/19	3.0	.538	60.5	2.165		
	83.6	9.7	69	70	20/20	3.0	.530	59.5	2.833		
	97.1	7.5	80	70	20/20	3.0	.582	60	2.336		
	111.5	14.4	81	70	20/20	3.0	.611	59.5	2.313		
	125.3	12.6	69	70	20/20	3.2	.510	48	1.677		
	137.3	7.0	69	70	20/20	7.6	.711	48	1.774		
	146.1	8.0	69	70	10/10	7.6	.803	48	1.303		
	159.4	9.3	69	70	10/10	7.6	.800	49	1.649		
	169.0	8.6	69	70	10/10	3.3	.579	48	1.569		CO_2 UNSTABLE
	183.9	14.3	69	70	10/10	3.0	.590	48	1.544		
	196.5	9.1	68	50	10/10	3.0	.561	48	1.337		
	210.7	12.0	70	10	10/10	3.0	.238	47	.209		
	224.4	9.7	70	20	10/10	3.0	.381	47	.406		
	238.5	13.1	69	10	10/10	7.6	.530	47	.244		
	252.5	12.0	69	10	20/20	7.6	.412	47	.261		
	265.8	9.9	69	10	20/20	3.0	.252	47	.386		
	277.1	11.3	69	10	40/40	3.0	.190	46.5	.310		
	292.1	9.3	69	10	40/40	7.6	.318	47	.264		
	306.3	8.3	80	10	20/20	3.0	.218	47	.257		
	320.4	10.4	78	10	20/20	3.0	.242	60.5	.452		
	335.4	10.2	70	10	20/20	3.0	.257	48	.351		
	349.5	10.7	70	10	10/10	3.0	.232	48	.241		
	362.1	8.0	72	50	20/20	3.0	.411	47	1.122		
	389.1	10.1	70	67	40/40	7.6	.469	46	1.172		
	402.8	9.2	70	67	40/40	3.0	.362	46	1.090		
	410.0	4.0	72	30	10/10	7.6	.717	47	.660		
	414.0	3.0	72	30	10/10	4.5	.607	47	.657		
	432.6	3.5	72	30	20/20	7.6	.597	47	.783		
	438.1	5.5	72	30	20/20	5.0	.462	47	.754		
	450.3	5.0	72	30	40/40	7.6	.420	47	.744		
SINGLE BED OPERATION	16.2	2.7	70	50	18/18	7.3	.312	46.5	.712	1978	
	40.0	19.3	70	50	18/18	7.4	.311	45.5	.630		
	56.5	10.7	70	50	10/10	7.5	.409	42	.615		
	65.6	7.2	70	30	10/10	7.2	.348	46.5	.562		

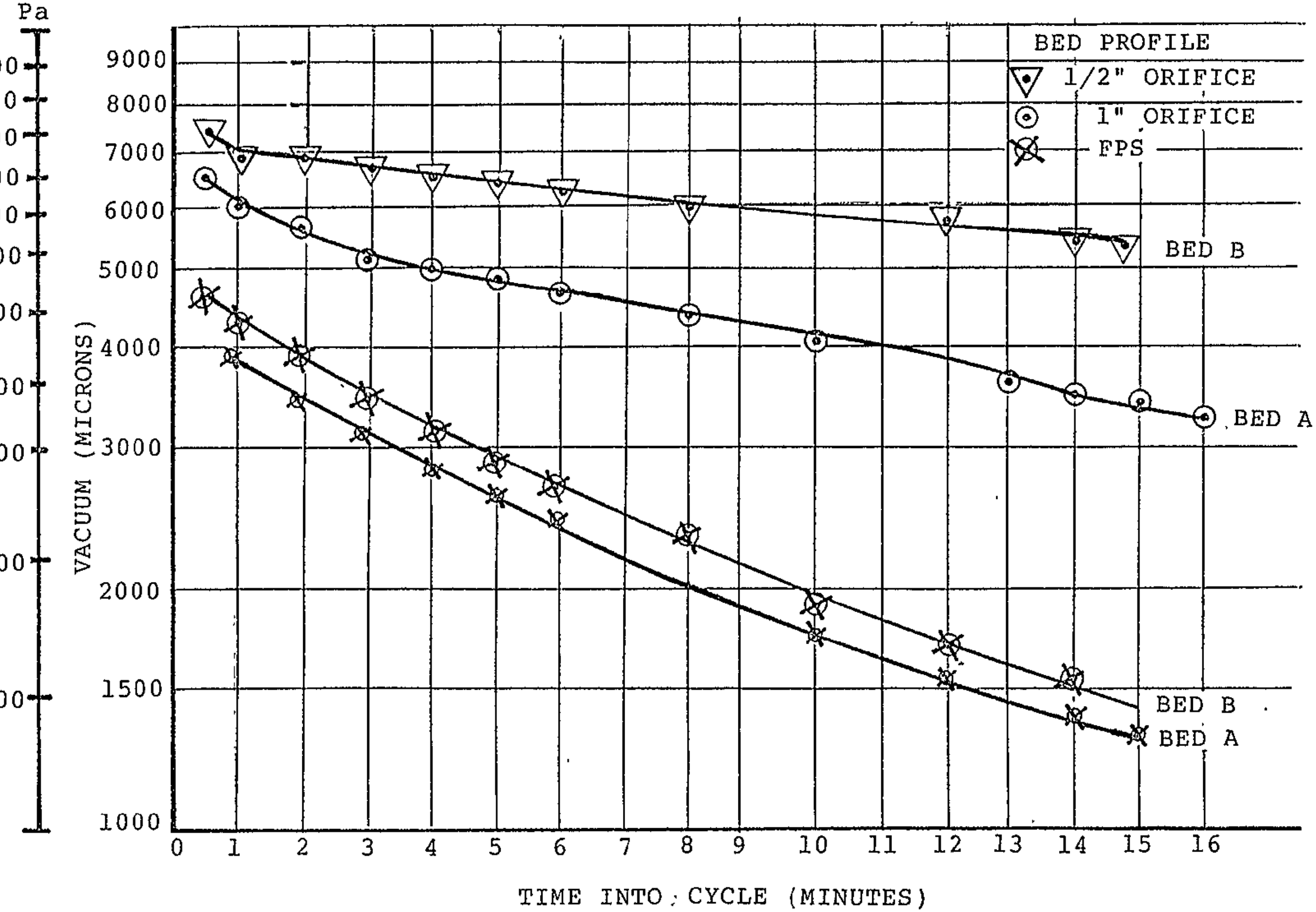
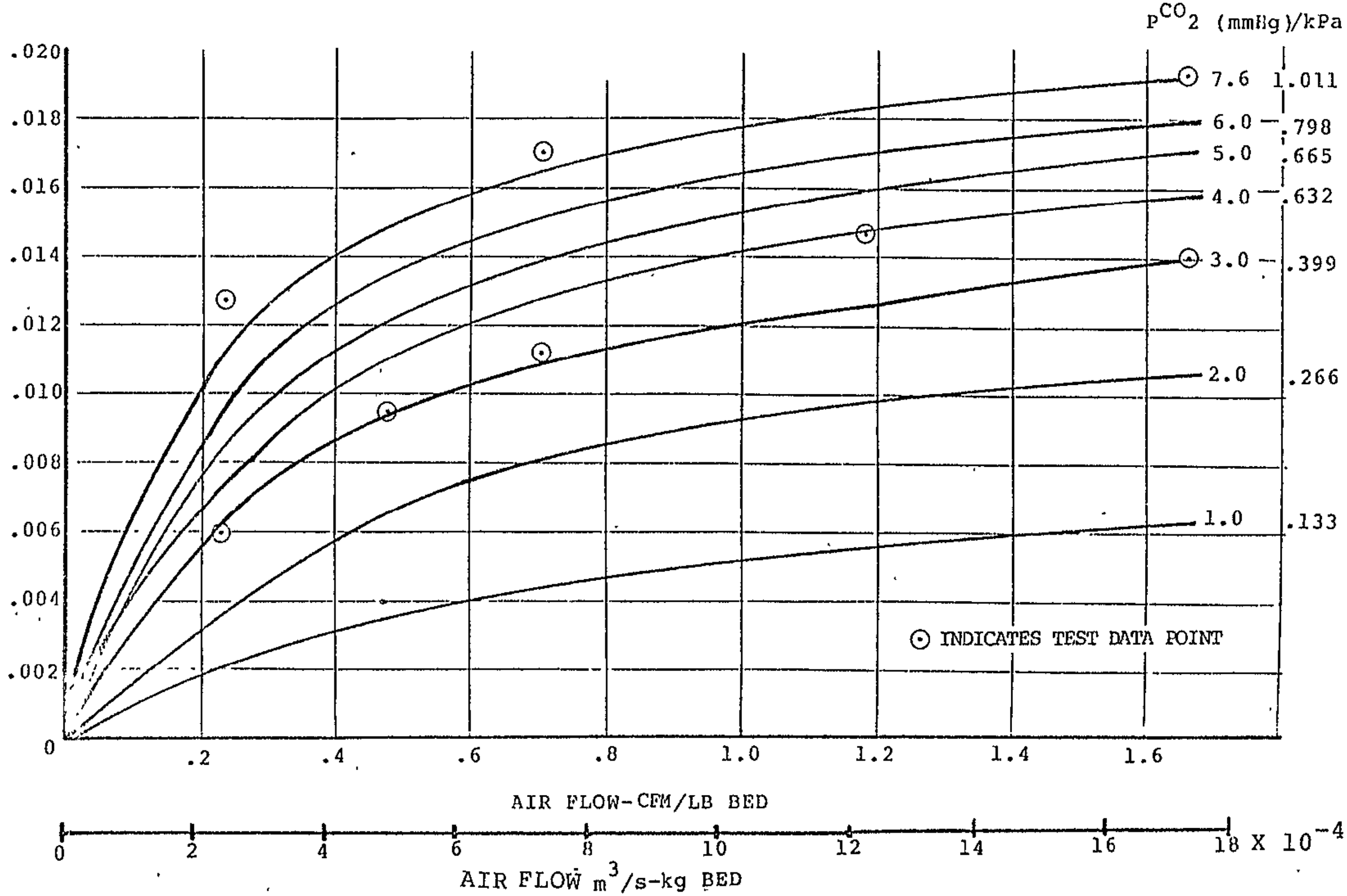


FIGURE 16
BED PRESSURE PROFILE

HAMILTON STANDARD
Division of UNITED TECHNOLOGIES



CO_2 REMOVAL RATE

FIGURE 17
SOLID AMINE PERFORMANCE MAP
10/10 CYCLE TIME

SVHSER7208

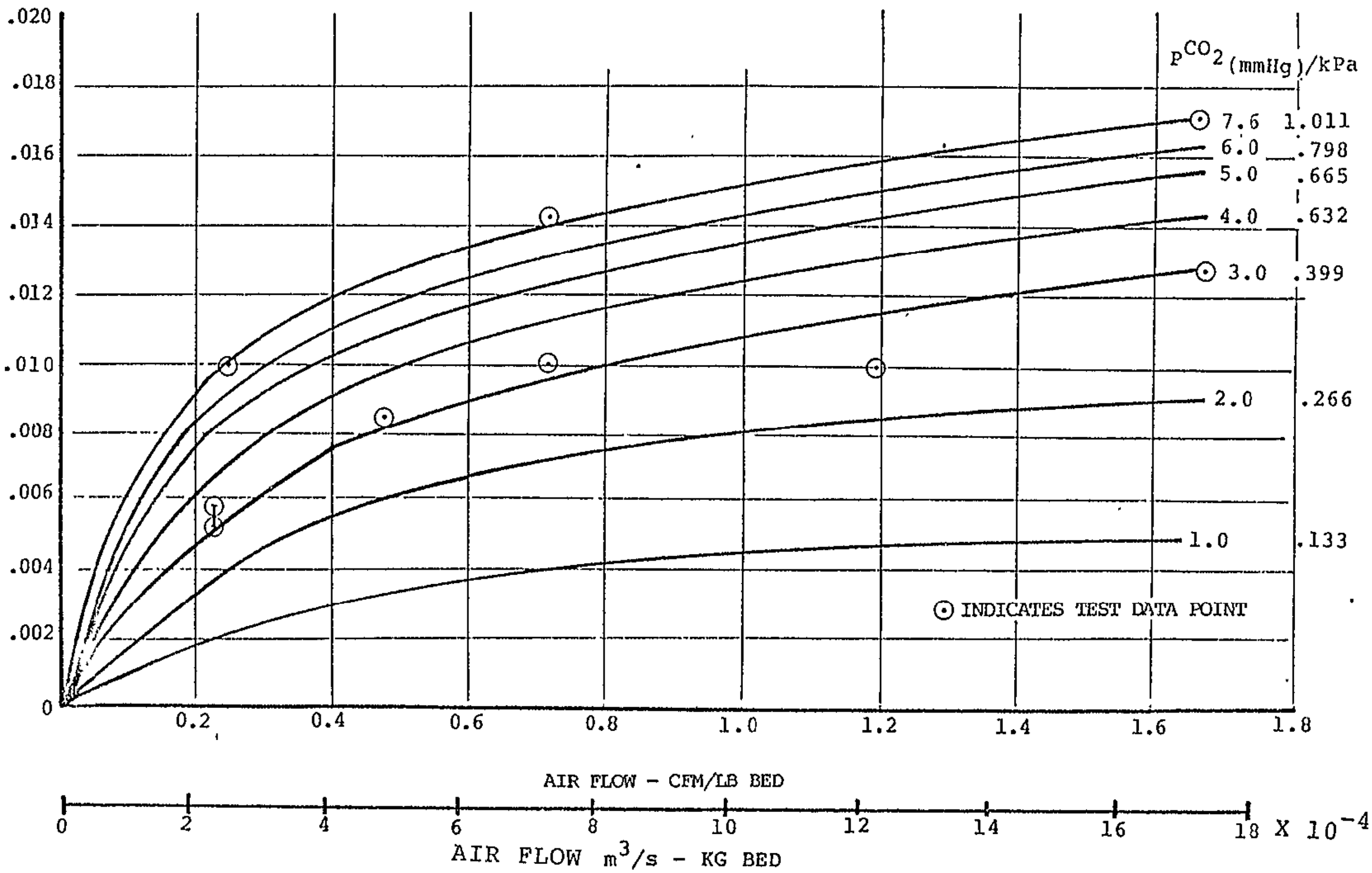


FIGURE 18
SOLID AMINE PERFORMANCE MAP
20/20 CYCLE TIME

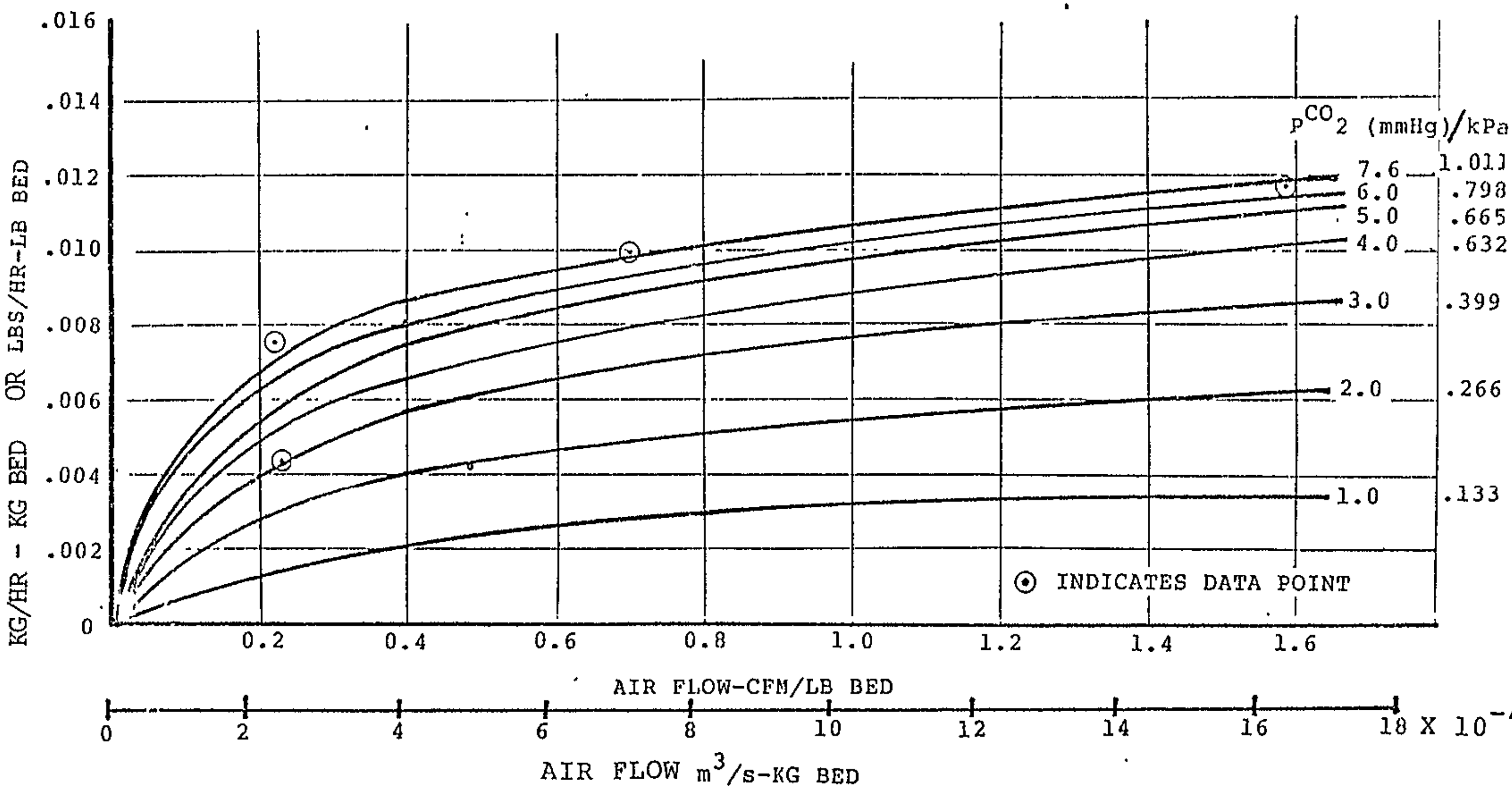


FIGURE 19
SOLID AMINE PERFORMANCE MAP
40/40 CYCLE TIME

Single Bed Operation

The objective of this test was to determine system performance when one bed of the canister was non-operable. This test simulated a valve or actuator failure on the prototype system since this failure would result in only one bed on line with the suspect bed isolated.

The prototype system filled with the newly fabricated HS-C material was used for the single bed testing. For the single bed testing, the vacuum valve linkage for Bed B of the prototype system was disconnected and secured to prevent leakage. The bypass valve was positioned to set the same bed ΔP as that measured with .024 m^3/s (50 cfm) airflow. The CO_2 and water feed rates were varied to maintain a 0.96 kPa (7.2 mmHg) CO_2 partial pressure and a dewpoint of 8.3°C (47°F).

With this degraded mode of operation, the system using a ten minute cycle and 0.24 m^3/s (50 cfm) airflow maintained an acceptable CO_2 partial pressure with a CO_2 removal rate equivalent to a four-man metabolic rate at 21.1°C (70°F). It was therefore concluded that the system could maintain acceptable CO_2 levels when operating in a degraded condition.

It is significant to note that, for identical conditions, one bed mode of operating removes only 42 percent of the CO_2 removed by a two-bed canister. For four-man missions, one bed can be used for a fail operational backup to the two-bed canister. The cycle rate must be reduced from 20 minutes to 10 minutes. One IMU fan will maintain the nominal metabolic CO_2 below 7.6 mmHg and the dew point at 47°F. Both fans are needed to handle the maximum metabolic CO_2 loading or reduce the nominal level to 6 mmHg. One bed cannot handle the maximum humidity load without assistance from the cabin heat exchanger.

The ullage penalty for this mode of operation doubles because of the 10-minute cycle time. This increase in ullage could potentially reduce the mission length by 10 percent if makeup gas supplies are budgeted that closely.

The effect of heat transfer in the canister design was proven by the one-bed testing. At the design point cycle time of 18 minutes, one bed, working alone, removed 42 percent of the CO_2 removed by the same canister with both bed operating. The effect of the thermal mass of the non-working adjacent bed can be seen from the temperature profiles of each bed as seen in Figure 20 and 21. The one operating bed has a higher average adsorbing temperature and a lower average desorbing temperature (Ave. = 18°F) than for two-bed operating (Ave. = 13°F), although the temperature extremes are the same. The thermal mass of the adjacent bed limits the temperature extreme of the operating bed. Were the beds to be thermally separated, poorer performance would be expected since a greater temperature swing would result in each bed.

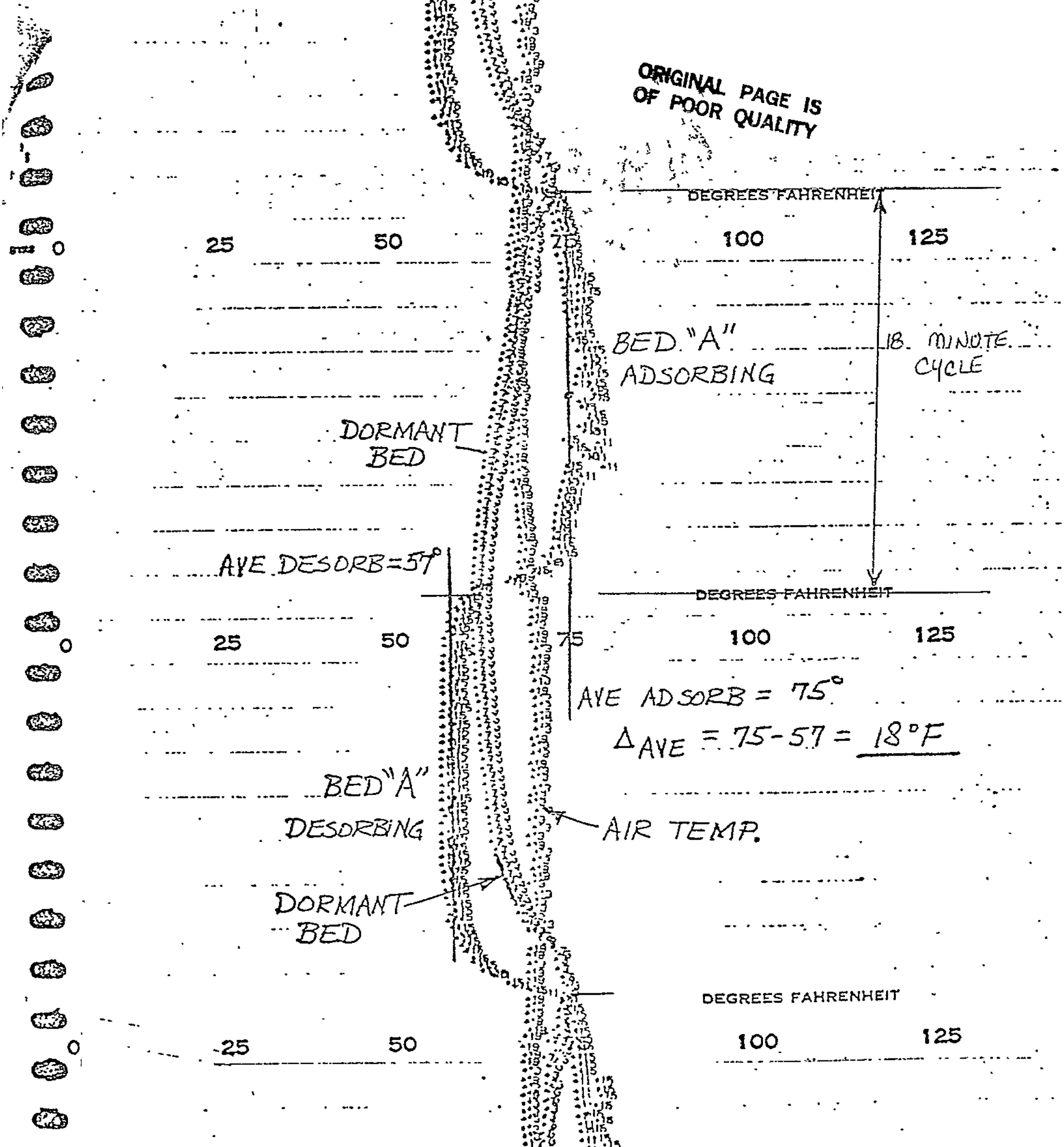


Figure 20
Temperature Profile
of One-Bed Operation
12-1-78 Data

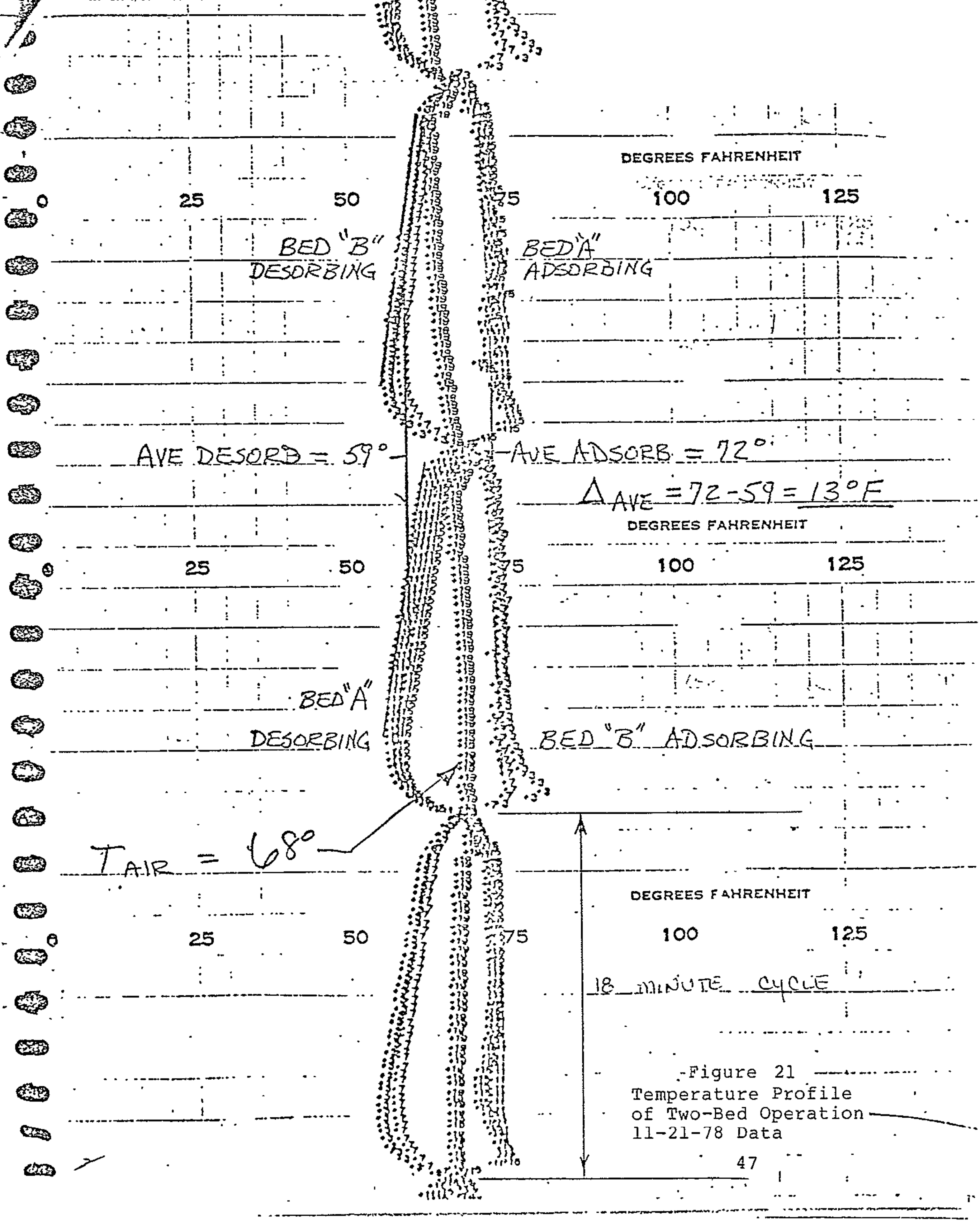


Figure 21
Temperature Profile
of Two-Bed Operation
11-21-78 Data

APPENDIX A

VIBRATION TEST DATA

HSF-175 1A 1/66

Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION
WINDSOR LOCKS, CONNECTICUT 06096

SPACE & LIFE SYSTEMS LABORATORY

LOG OF TEST

TYPE OF TEST: DEV

TEST ENGINEER: R MICKET

NAME OF RIG: 26.

PROJECT & ENG ORDER NO: B11-122-100A

SHEET 1 OF

DATE 02 JUN 78

TEST PLAN NO: VERBAL

MODEL NO.: HSC COMPONENT

PART NO.: – no pulsed

SERIAL NO.: –

OPERATORS: P. JODOIN / J. MORSE

RUN NO		TIME START		AXIS		MODE		G'S RMS		DURATION MINS
2		1033		X		RAND.		13.9		48.0
3		1339		Y		RAND.		13.9		48.0
4		1111	05JUNE	Z		RAND		13.9		48.0

A-1

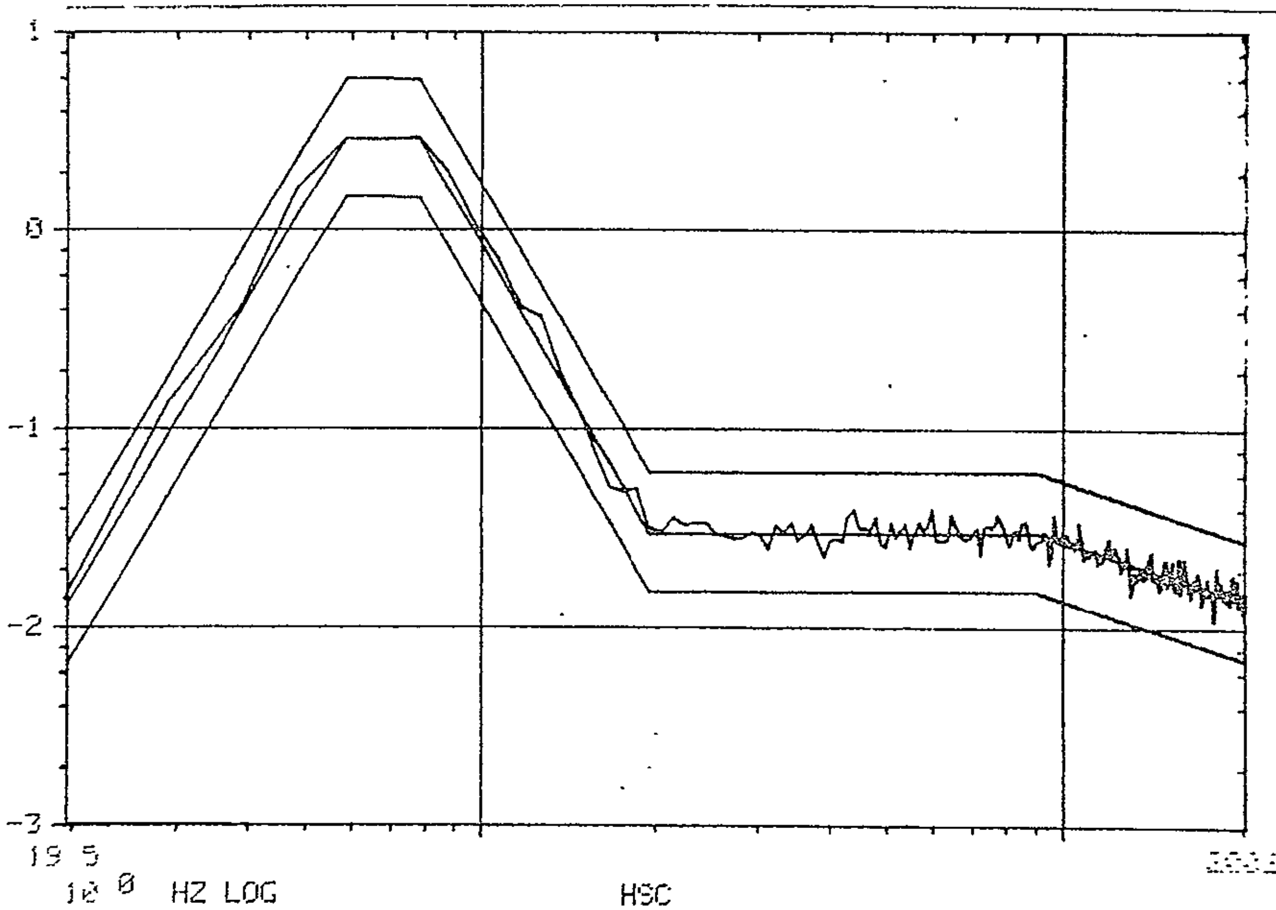
ORIGINAL PAGE IS OF POOR QUALITY

REMARKS

20632

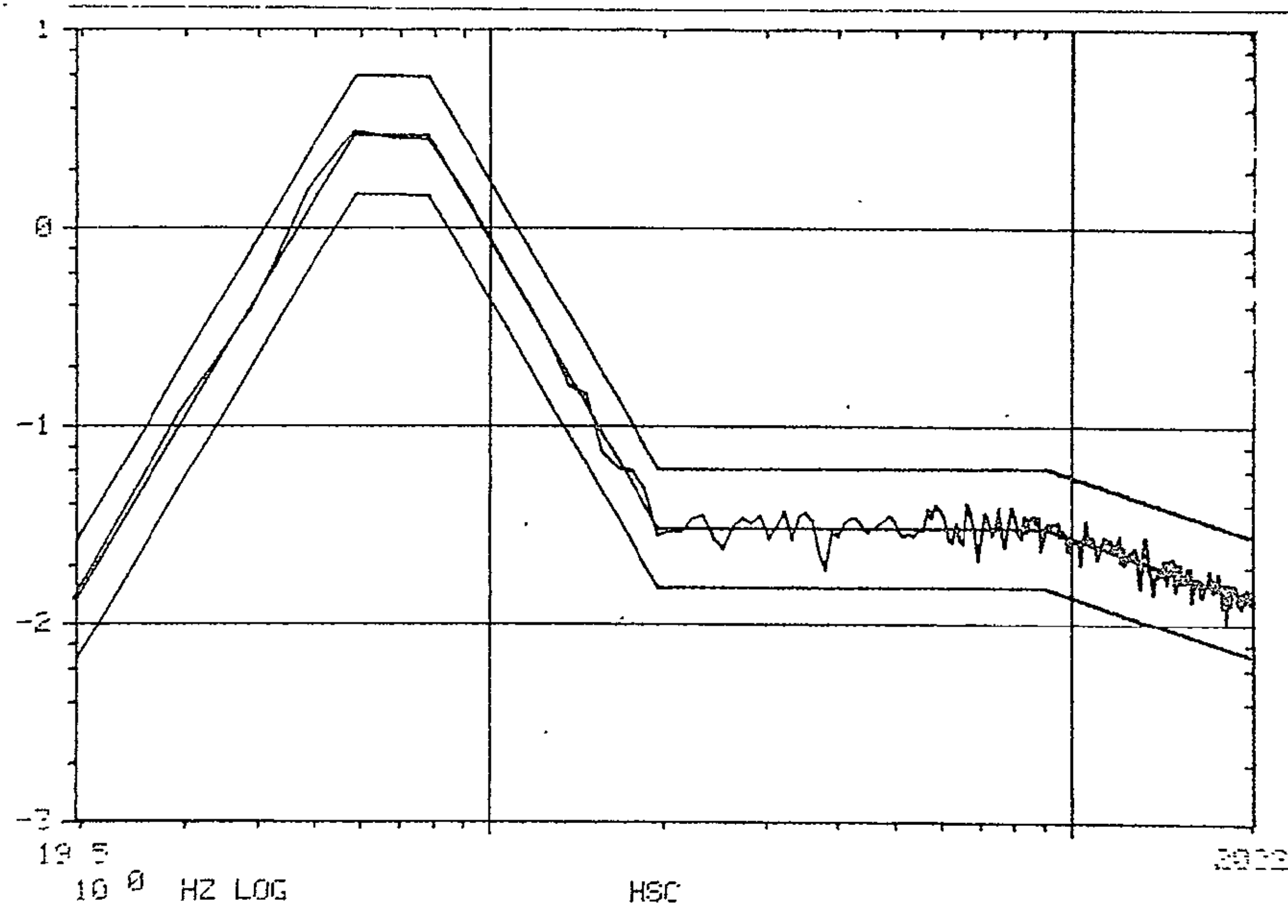
SVHSER 7208

RUN NO 2, X AXIS, 06/02/78
POST TEST   ELAPSED TIME =   992 SECS AT   00 DB
RMS LEVEL = 14.25 G'S   DELTA F = 9.766   DOF= 61   AWF= 16
G SQR/HZ



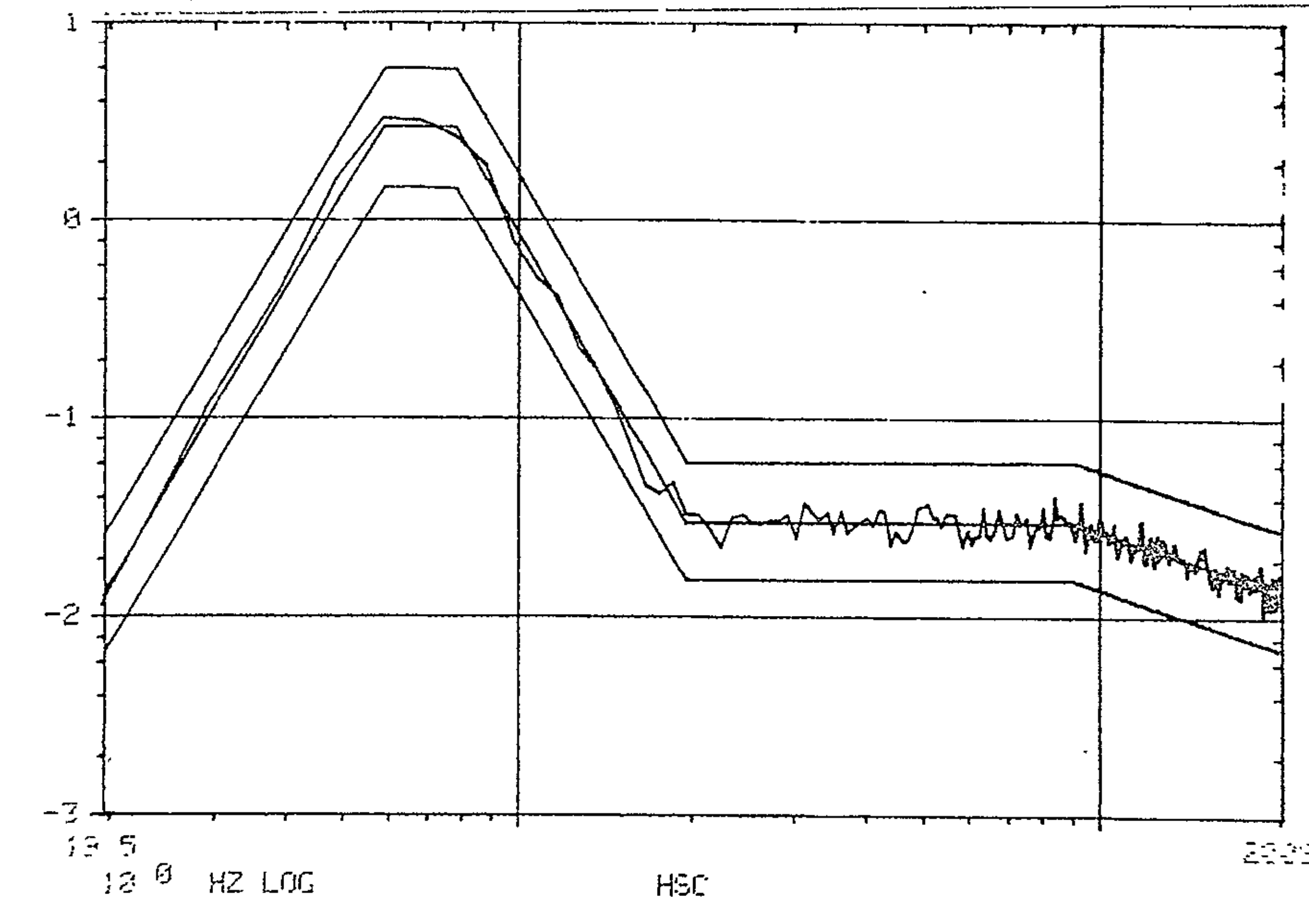
BED WITH NO PRELOAD

LAST PART OF RUN NO. 2, X AXIS, 06/02/78
POST TEST ELAPSED TIME = 1889 SECS AT 00 DB
RMS LEVEL = 13.97 G'S DELTA F = 9.766 DOF=61 AWF= 16
G SQR/HZ



BED WITH NO PRELOAD

RUN NO 3, Y AXIS, 06/02/78
POST TEST ELAPSED TIME = 2880 SECS AT 00 DB
RMS LEVEL = 14.04 G'S DELTA F = 9.766 DOF= 61 AWF= 16
G SQR/HZ

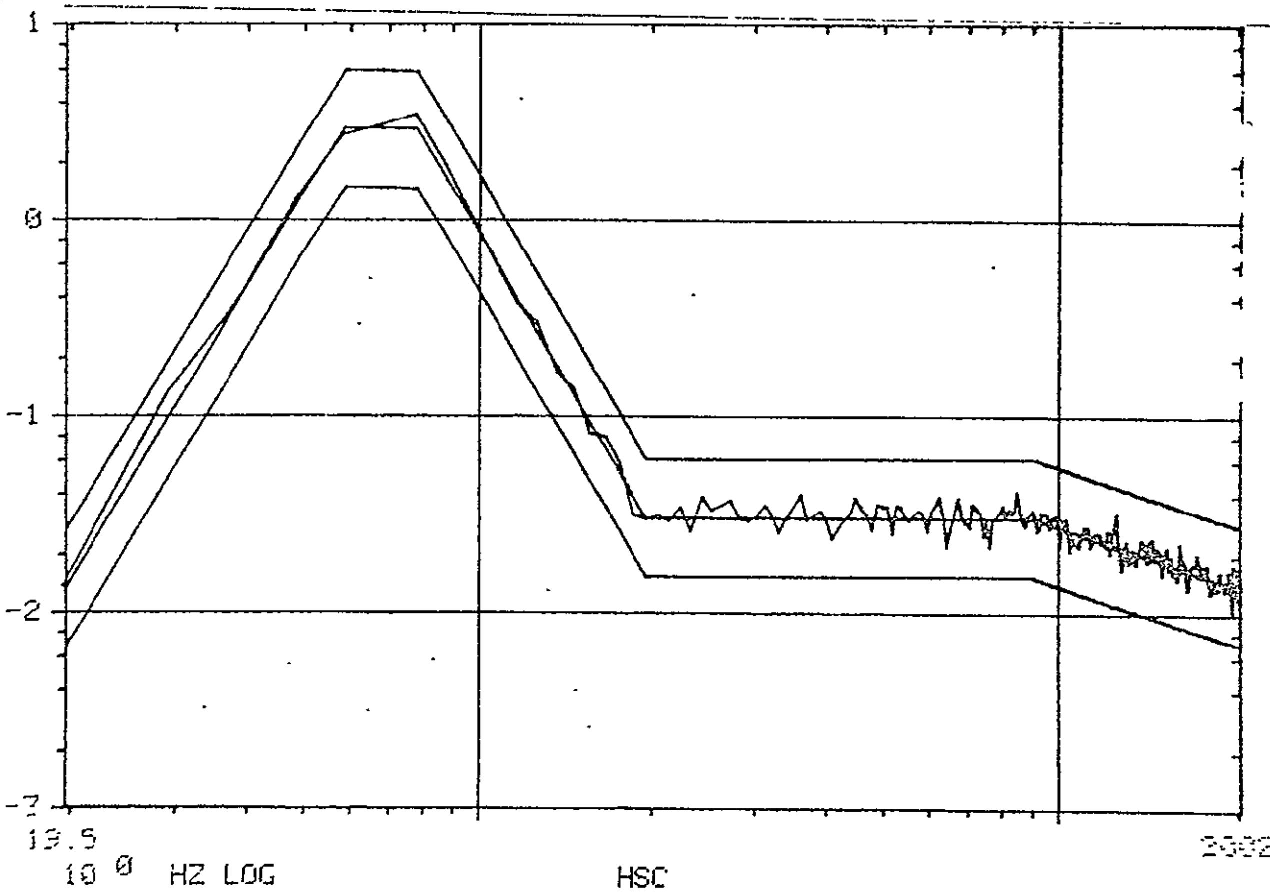


BED WITH NO PRELOAD

RUN NO 4, Z AXIS, 6/05/78
POST TEST
RMS LEVEL = 14.20 G'S

ELAPSED TIME = 2880 SECS AT 00 DB
DELTA F = 9.766 DOF= 61 AWF= 16

G SQR/HZ



BED WITH NO PRELOAD

HSF-175 1A 1/66

Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION
WINDSOR LOCKS, CONNECTICUT 06096

SPACE & LIFE SYSTEMS LABORATORY

LOG OF TEST

TYPE OF TEST DEV

TEST ENGINEER R. MICKET

NAME OF RIG 26

PROJECT & ENG. ORDER NO. B11-122-100A

SHEET 1 OF | DATE 7/5/78

TEST PLAN NO.

MODEL NO. HSC COMPONENT

PART NO. PRELOAD BED

SERIAL NO

OPERATORS JODOIN / MURSE

RUN NO	DATE	TIME HR		AXIS		MODE		G's RMS		DURATION MINS
2	7/7/78	1315		Z		RAND		13.9		48.0
3	7/10/78	1244		Y		RAND		13.9		48.0
4	7/11/78	0835		X		RAND		13.9		48.0

REMARKS:

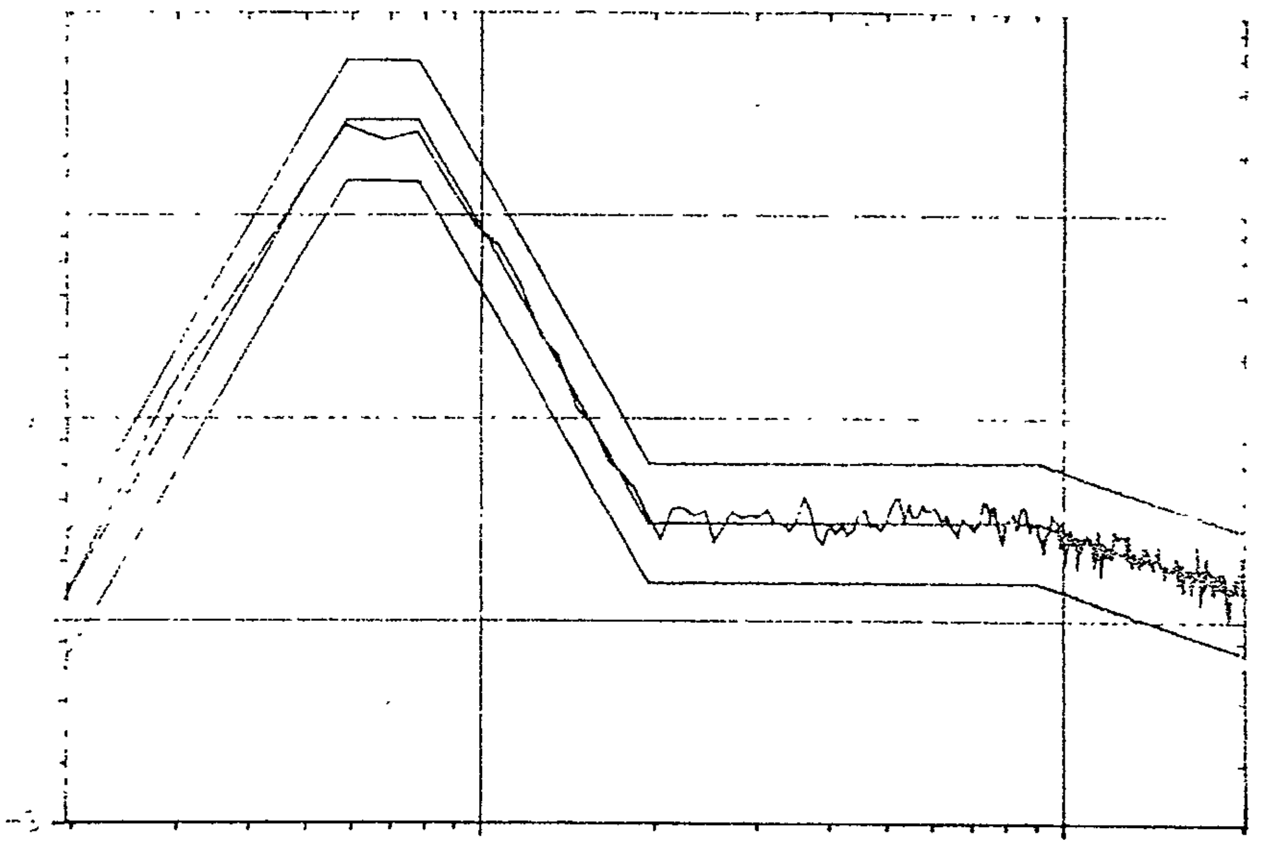
A-6

20648

SVHSER 7208

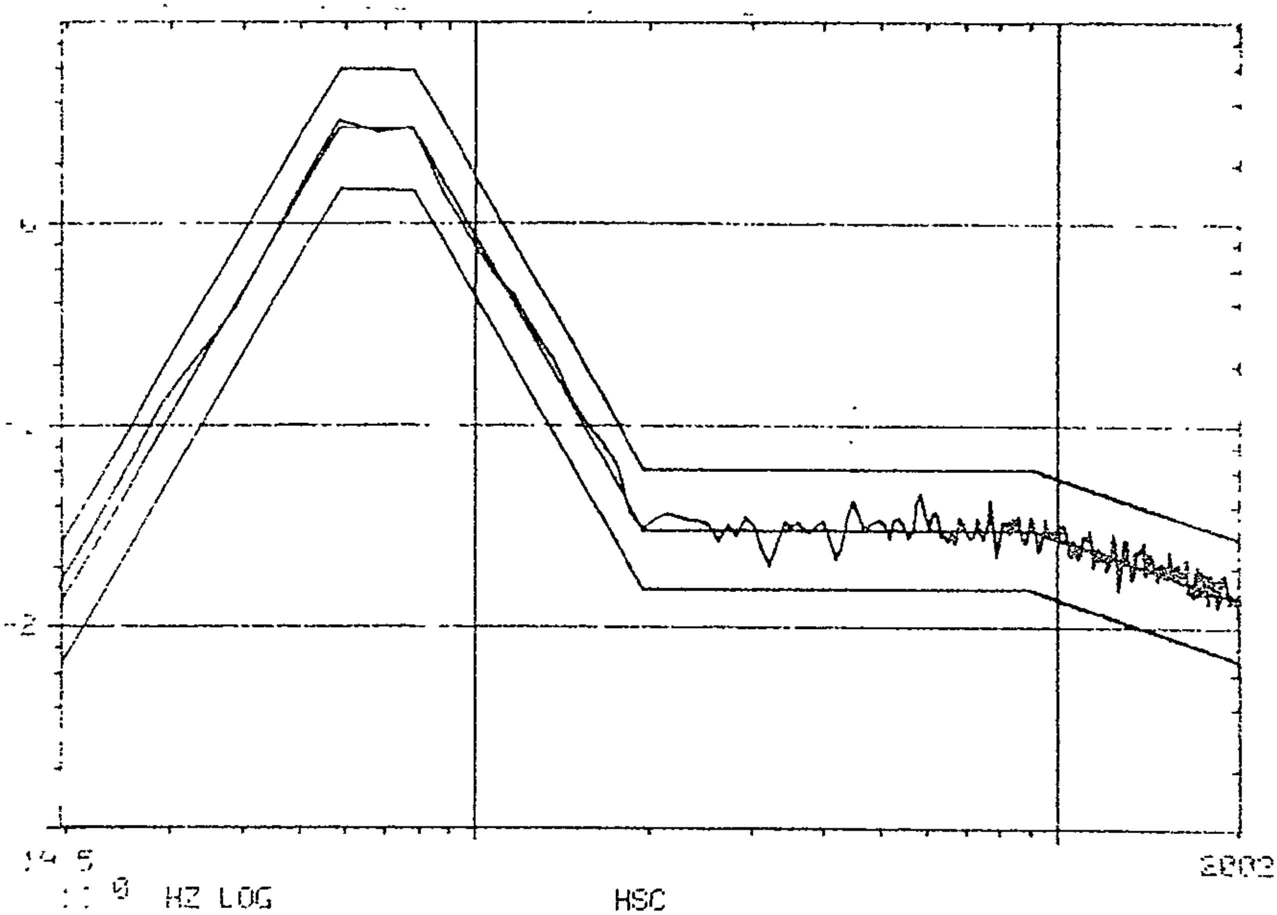
RUN NO 4, X-AXIS AX CNTRL 7/11/78
POST TEST
RMS LEVEL = 13.47 G'S
G SQR/HZ

ELAPSED TIME = 2880 SECS AT 00 DB
DELTA F = 9.766 DOF= 61 AWF= 16



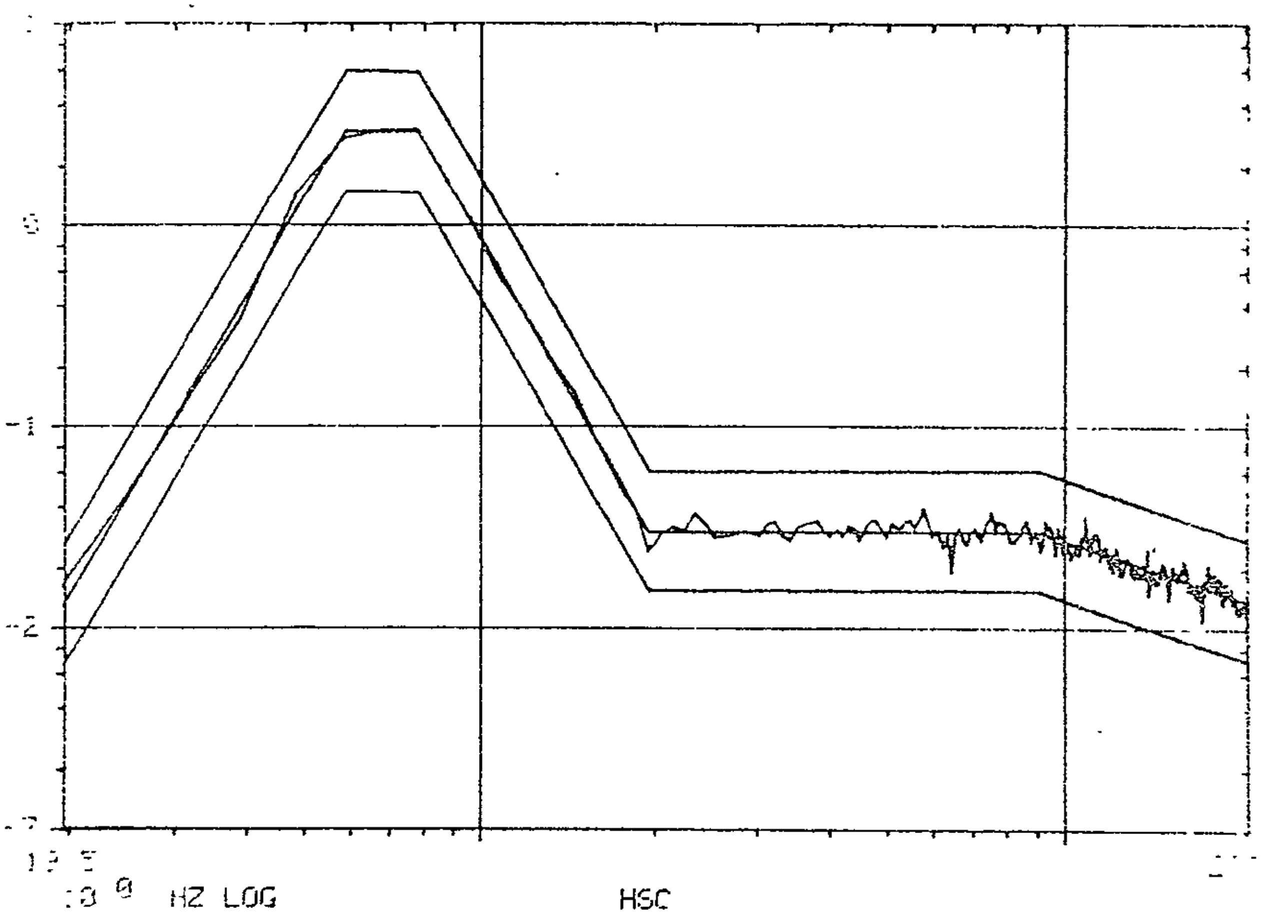
BED WITH PRELOAD

Y-AXIS RUN # 3 AY CNTRL 7/10/78
POST TEST ELAPSED TIME = 2793 SECS AT 00 DB
RMS LEVEL = 13.92 G'S DELTA F = 9.766 DOF= 61 AWF= 16
G SQR/HZ



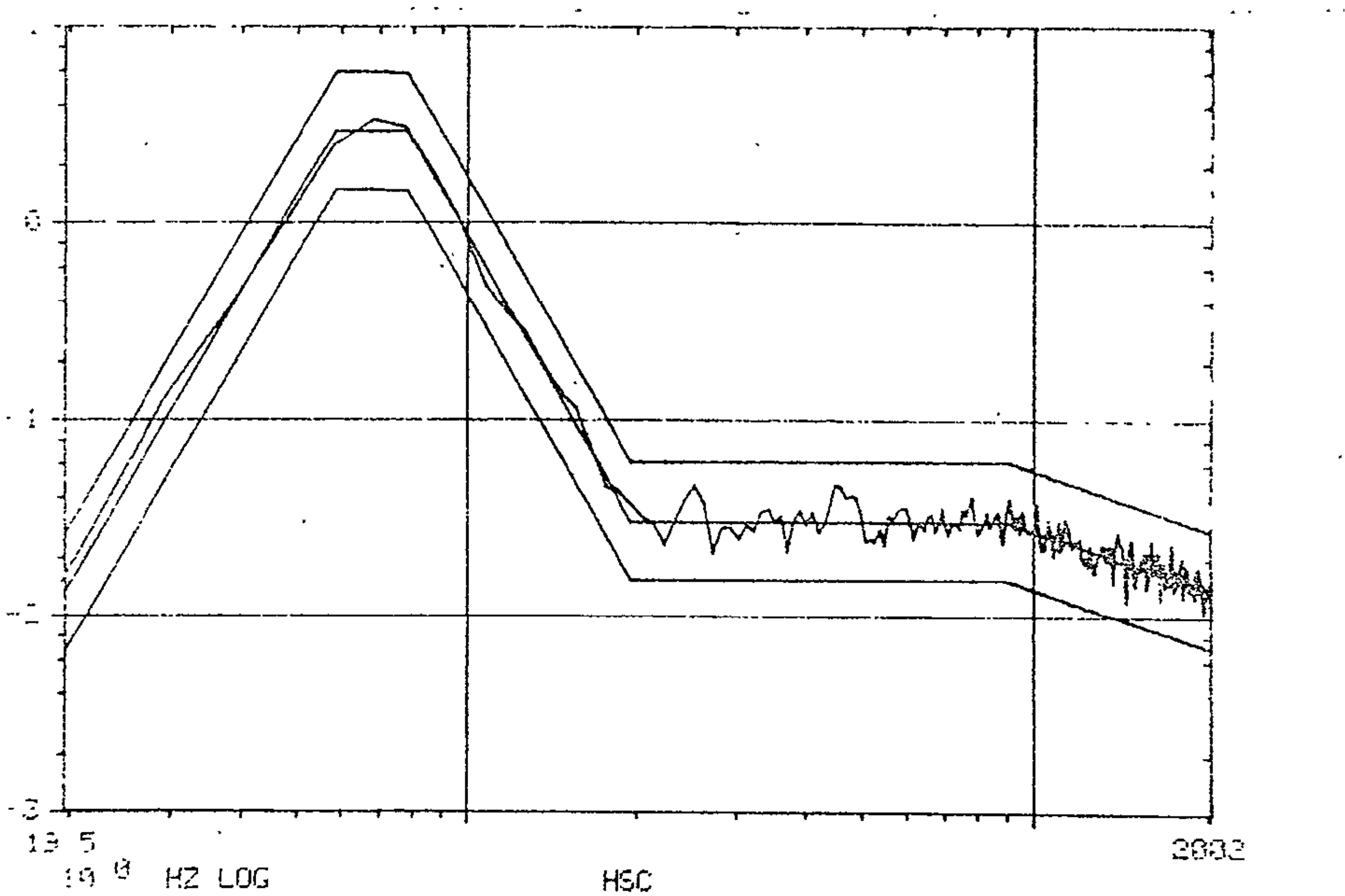
BED WITH PRELOAD

POST TEST ELAPSED TIME = 102 SECS AT 00 DB
RMS LEVEL = 13.83 G'S DELTA F = 9.766 ODF= 61 AWF= 16
G SQR/HZ



BED WITH PRELOAD.

RUN # 2 Z-AXIS AZ CNTRL 7/7/78
POST TEST ELAPSED TIME = 2880 SECS AT 00 DB
RMS LEVEL = 13.90 G'S DELTA F = 9.766 DOF= 61 AWF= 16
G SQR/HZ



BED WITH PRELOAD

APPENDIX B

PLAN OF TEST

HAMILTON STANDARD Division of UNITED TECHNOLOGIES

SVHSER 7208

FLIGHT PROTOTYPE REGENERABLE CO_2 AND H_2O CONTROL SYSTEM

PLAN OF TEST FOR MATERIAL EVALUATION

PREPARED UNDER CONTRACT NAS 9-13624

BY

HAMILTON STANDARD

DIVISION OF UNITED TECHNOLOGIES CORPORATION

WINDSOR LOCKS, CONNECTICUT

FOR

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

LYNDON B. JOHNSON SPACE CENTER

HOUSTON, TEXAS

APRIL, 1978

PREPARED BY: K M Rudy
K. M. RUDY
PROGRAM ENGINEER

G. N. Kleiner
G. N. KLEINER
R&D ENGINEERING MANAGER

APPROVED BY: H F Brose
H. F. BROSE
PROGRAM MANAGER

1.0 INTRODUCTION

1.1 This Plan of Test defines the testing of the Flight Prototype Regenerable CO_2 and H_2O Control System, SVSK 91725, under Contract NAS 9-13624 as required by contract Modification 20S.

2.0 PURPOSE

2.1 This test will investigate the effect of age on the HS-C material performance. The test will verify the repeatability of the HS-C fabrication process.

3.0 The test setup shall be closed loop. The HS-C system and Rig 88 shall be plumbed in series and will feed into and out of a cabin volume simulation. Vacuum desorption will be accomplished using Rig 52 connected to the HS-C system. CO_2 and water must be supplied.

3.1 A list of required instrumentation is given in Table I.

3.2 A schematic test setup is given in Figure I.

4.0 TEST PROGRAM

4.1 Test Sequence - Testing of the HS-C system shall consist of HS-C system evaluation and rig checkout in the following sequence:

Sequence	Test	Section Ref.
1	Leakage and Instrument Calibration	4.2.1
2	System and Bypass Flow Calibration	4.2.2
3	System Performance Baseline	4.2.3
4	Leakage and Instrument Calibration	4.2.4
5	System and Bypass Flow Calibration	4.2.5
6	System Performance Calibration	4.2.6

4.2 Description of Tests

4.2.1 Leakage and Instrument Calibration

4.2.1.1 Canister and System Vacuum Leakage

4.2.1.1.1 Purpose - The purpose of this test is to ensure that the leakage of the vacuum portion of the Flight Prototype System, including the canister, is sufficiently below the vacuum rig pumping rate to allow desorption of the HS-C beds.

4.2.1.1.2 Description of Test Setup

4.2.1.1.2.1 A schematic of the test setup is given as figure 1 of this plan.

4.2.1.1.2.2 Instrumentation shall include a pressure gage readout for each side of the system and a stop clock. These instruments are defined in Table 1.

4.2.1.1.2.3 Test rigs and equipment are the Flight Prototype System.

4.2.1.1.3 Procedure

a) Rig 52 shall be operating.

b) Actuate the Flight Prototype System so that Bed "A" is in the desorb mode, and Bed "B" is in the adsorb mode.

c) Using the ullage-save compressor, evacuate Bed "A" below 2.0 psia.

d) Turn-off and valve-off the ullage-save compressor.

e) Measure and record the pressure rise in Bed "A" every 10 minutes for a 30 minute period.

f) Repeat steps (b) through (e) for Bed "B".

4.2.1.1.4 Special Instructions

a) Calculate the total evacuated volume by adding the known canister volume to the calculated plumbing volume.

b) Calculate the leakage by the formula:

$$\text{leakage} = 0.3\ \frac{(\text{Volume})(\text{Delta Pressure})}{\text{time}}\ \frac{(14.7)}{(14.7\text{-Press})}$$

4.2.1.1.4 (Continued)

where: leakage = lb/hr
Volume = ft^3
Delta Pressure = psi
time = minutes
Press = Evacuated Press = psia

c) This test shall be considered acceptable if each bed has a leakage of less than 0.01 lb/hr.

4.2.1.2 Pressure Capability of the Plenum

4.2.1.2.1 Purpose - The purpose of this test is to establish the ability of the plenum and interfacing rigs to hold pressure.

4.2.1.2.2 Description of Test Setup

4.2.1.2.2.1 A schematic of the test setup is given as figure 1 of this plan.

4.2.1.2.2.2 Instrumentation shall include a barometer, U tube manometer, and thermocouples. These instruments are defined in Table 1.

4.2.1.2.2.3 Multipurpose Test Rig 88 and the flight prototype system shall be plumbed to the plenum. A shop air line shall be plumbed to the plenum for this test.

4.2.1.2.3 Procedure

a) The plenum shall be calibrated for its ability to hold a positive pressure. The plenum shall be pressurized with "shop air" to ten inches of water pressure. A plot of the pressure decay of the plenum with time shall be taken.

b) All vacuum valves in the breadboard system shall be in the closed position for this test.

c) The test shall be terminated when ambient pressure is reached in the plenum or after sixteen hours. The time to reach ambient pressure shall be recorded together with pressure versus time data.

d) Plenum temperature shall be recorded during the test.

4.2.1.3 Instrument Calibration

4.2.1.3.1 Purpose - The purpose of this calibration is to verify test measurements by demonstrated calibration before and after data collection.

4.2.1.3.2 Description of Setup

a) The Infra-red CO_2 Analyzer shall be calibrated in place, using calibration gases.

b) The hygrometer shall be calibrated on the Advanced Engineering setup located in Advanced Engineering Laboratory.

c) The vacuum pressure transducers shall be calibrated, per accepted procedures, by the Instrumentation and Metrology department.

4.2.1.3.3 Procedure - The following instruments shall be calibrated per accepted procedures:

a) Infra-Red CO_2 Analyzer at 0, 0.5 and 1.0% CO_2.

b) Hygrometers, including readout, over a range of 0 to 75°F, approximately equally spaced.

c) Vacuum pressure transducers, including readouts, over their full scale.

4.2.1.3.4 Special Instructions

a) The Infra-Red Analyzer data shall be plotted, CO_2 pressure versus scale %, and used as a calibrated curve.

b) The hygrometer and pressure transducer data shall be presented as a tabulated error chart.

4.2.2 System and Bypass Flow Calibration

4.2.2.1 Purpose - The purpose of this test is to establish air flow through the HS-C bed and thus bypass flow as a function of pressure drop across the bed.

4.2.2.2 Description of Test Setup

4.2.2.2.1 A schematic of the test setup is given as figure 1 of this plan.

4.2.2.2.2 Instrumentation shall include thermocouples and readout, Rig 88 flow sensing venturi, and U tube manometer. These instruments are defined in Table 1.

4.2.2.2.3 Rig 88 and the HS-C system are required.

4.2.2.3 Procedure

a) Power Rig 88 and adjust the outlet valve to give 70 $\pm$ 2 cfm air flow. Measure the bed pressure drop at this condition for Bed A.

b) Adjust the Rig 88 outlet valve and measure Bed A pressure drop versus flow at a minimum of 10 flows from zero (0) to 80 cfm.

c) Repeat steps (a) and (b) for Bed B.

4.2.2.4 Special Instructions - A plot of flow versus bed pressure drop shall be prepared for each bed. The bypass valve can then be positioned to achieve the desired bed pressure drop for any given flow condition.

4.2.3 System Performance Calibration

4.2.3.1 Purpose - The purpose of this test is to establish the baseline performance of the HS-C prototype system when filled with HS-C material fabricated four years ago.

4.2.3.2 Description of Test Setup

4.2.3.2.1 A schematic of the test setup is given as Figure 1 of this plan.

4.2.3.2.2 All instrumentation shown on Figure 1 and defined by Table 1 is required.

4.2.3.2.3 Rigs 52 and 88 are required. The Cabin Volume Simulation shall be utilized.

4.2.3.2.4 The canister shall be provided with special instrumentation. Two adjacent layers in the middle of the canister shall incorporate thermocouples, inserted to a depth of approximately 2 inches into the foam. One layer shall be fitted with a pressure transducer to monitor vacuum levels at the end of the bed.

4.2.3.3 Procedure

4.2.3.3.1 General

b) At the start and end of each run the gross weight of CO_2 and water shall be noted. Steam generator setting shall be recorded throughout each run.

b) As a minimum, the temperature and pressure, instrumented per paragraph 4.2.3.2.4, shall be recorded at two-minute intervals for two continuous cycles. The test condition must be stabilized. This data shall also be recorded on the multipoint recorder whenever possible.

4.2.3.3.2 Set the cycle time for 18 minutes adsorb/18 minutes desorb including the ullage-save compressor cycle.

4.2.3.3.3 Establish the cabin environment for the 7-man crew; establish 50 cfm air flow through the HS-C system.

Air Temperature	80° $\pm$ 2°F
Cabin Pressure	14.7 $\pm$ 0.5 psia
Cabin Volume	1035 $\pm$ 5% ft^3
Cabin Dew Point	60°F max.
CO_2 Pressure	4.5 mmHg nominal
CO_2 Flow	.615 $\pm$ 0.5% lb/hr
H_2O Flow	1.61 $\pm$ 2.0% lb/hr

4.2.3.3.4 Adjust CO_2 and H_2O feed rates, as necessary, to maintain an average value of 4.5 mmHg PCO_2 and 59°F dew point.

4.2.3.3.5 Establish the cabin environment for the seven-man crew at 65°F environment:

Air Flow	50 cfm
Air Temperature	65° $\pm$ 2°F
Cabin Pressure	14.7 $\pm$ 0.5 psia
Cabin Volume	1035 $\pm$ 5% ft^3
Cabin Dew Point	39°F nominal
CO_2 Pressure	7.0 mmHg nominal
CO_2 Flow	.615 $\pm$ 0.5% lb/hr
H_2O Flow	.77 $\pm$ 2% lb/hr

4.2.3.3.6 Adjust CO_2 and H_2O feed rates as necessary to maintain an average value of 7.0 mmHg PCO_2 and 39°F dew point.

4.2.3.3.7 A minimum of 60 hours shall be accumulated during this test.

4.2.3.4 Special Instructions

4.2.3.4.1 Data shall be hand tabulated for the following parameters: plenum temperature, PCO_2 and dew point, CO_2 flow rate, steam flow setting, system air flow, and cycle time. Times, absolute and elapsed, at which data is taken and/or conditions are changed shall be recorded.

4.2.3.4.2 Rig 88 Hygrometer and Infra-red Analyzer data shall be recorded on a multipoint recorder. Bed temperature and vacuum data shall be recorded whenever possible.

4.2.4 Leakage and Instrumentation Calibration

4.2.4.1 The prototype system shall be removed from the test setup and the HS-C material removed.

4.2.4.2 The canister will be refilled with newly-fabricated HS-C material and the prototype system reinstalled into the test setup.

4.2.4.3 Tests shall be conducted per paragraph 4.2.1 to assure that the prototype system has been installed properly.

4.2.5 System and Bypass Flow Calibration

4.2.5.1 Purpose - The purpose of this test is to establish air flow through the HS-C bed as a function of pressure drop across the bed.

4.2.5.2 The test shall be conducted per paragraph 4.2.2.

4.2.6 System Performance

4.2.6.1 Purpose - The purpose of this test is to demonstrate the performance of the flight prototype system using the newly fabricated HS-C material. This test will verify the repeatability of the HS-C fabrication process.

4.2.6.2 The test shall be conducted per paragraph 4.2.3 for the seven-man crew at 80°F environment.

4.2.6.3 The test shall be conducted per paragraph 4.2.3 for the seven-man crew at 65°F environment.

4.2.6.4 The test shall be conducted per paragraph 4.2.3 for the four-man crew at 65°F environment:

Air Flow	50 cfm
Air Temperature	65 $\pm$ 0.5 psia
Cabin Pressure	14.7 $\pm$ 0.5 psia
Cabin Volume	1035 $\pm$ 5% ft^3
Cabin Dew Point	35°F minimum
CO_2 Pressure	7.0 mmHg nominal
CO_2 Flow	.42 $\pm$ 0.5% lb/hr
H_2O Flow	.78 $\pm$ 2.0% lb/hr

4.2.6.4.1 Set the cycle time for 40 minutes adsorb/40 minutes desorb including the ullage-save compressor cycle.

4.2.6.4.2 Maintain the CO_2 and H_2O feed rates at the seven-man nominal feed rates.

4.2.6.5 A minimum of 120 hours of testing will be accumulated on the prototype system using the newly fabricated HS-C material.

5.0 SPECIAL INSTRUCTIONS FOR TESTING PROGRAM

5.1 Flight prototype system operation may be shut down when a change in temperature is required.

5.2 Operation of Rig 52 must be monitored by Operations personnel. Engineering shall advise Operations of the required periods of rig operation and shall instruct Operations personnel of procedures in the event of equipment problems.

5.3 "Equilibrium" shall be defined as the value of a parameter measured at consistent points in each cycle for three consecutive cycles whose trend extremes do not exceed $\pm$ 5%.

5.4 Instrumentation Calibration

5.4.1 All appropriate instrumentation indigenous to Rig 88 shall be calibrated prior to testing and shall be maintained per Rig Manual Form HSF-1881.

5.4.2 The Hygrometer and Infra-red Analyzer shall be calibrated prior to testing and as stipulated in the test sequence.

5.4.3 The Infra-red Analyzer shall be checked for 0 and 100% a minimum of once, prior to recording data, on each day of use. Similarly, the Hygrometer shall be "tested" a minimum of once, prior to recording data, on each day of use.

6.0 DATA USAGE AND PRESENTATION

6.1 Independent variables shall be time averaged and extremes of variation defined during steady state operation.

6.2 Dependent Variables

6.2.1 During steady state operation, dependent variables shall be time averaged with extremes defined.

6.2.2 Transients between different operating loadings shall be plotted versus time.

TABLE 1
DATA REQUIREMENTS AND INSTRUMENTATION LIST

Parameter	Units	Accuracy	Instrument	Range and Units	Notes
Rig 88 and HS-C Flow	cfm	± 10%	Venturi/Manometer	0 to 30 in H_2O	Indigenous to Rig 88
Rig 88 Outlet Temperature	°F	± 2°	Thermocouple	20 to 150°F	
Makeup CO_2 Flow	lb/hr	± 2% Full Scale	Flowrater	0 to 1.2 lbm/hr	
Makeup H_2O Flow	lb/hr	± 5%	Metering Valve	0 to 3.3 lbm/hr	
HS-C Inlet Temperature	°F	± 2°	Thermocouple	20 to 150°F	
HS-C System Cycle Time	minutes	± 1% Cycle	Stop Clock	0 to 60	
HS-C System Vacuum		± 5% Non-Linear Scale	Hastings Gage and Pickup or Equivalent	0 to Atmos	
HS-C Bed Press. Delta	in H_2O	± 0.05	U-Tube Manometer	0 to 20 inches	
Plenum Temperature	°F	± 2°	Thermocouple	20 to 150°F	
Plenum Dew Point	°F	± 2°	Hygrometer	-40 to 120°F	Indigenous to Rig 88
Plenum PCO_2	mmHg	± 2% Full Scale	Infra-Red Analyzer	0 to 100% (100% = TBD mmHg)	Indigenous to Rig 88
Plenum/Ambient Press. Delta	in H_2O	± 0.2	U-Tube Manometer	0 to 30 inches	Indigenous to Rig 88
Weight Makeup Air	lbm	± 0.02	Scale	0 to 300 lb	
Weight Makeup CO_2	lbm	± 0.02	Scale	0 to 300 lb	
Weight Makeup H_2O	lbm	± 0.02	Scale	0 to 300 lb	
Ambient Pressure	in. Hg	± 0.05	Barometer		
Ambient Temperature	°F	± 2°	Thermometer	20 to 400°F	

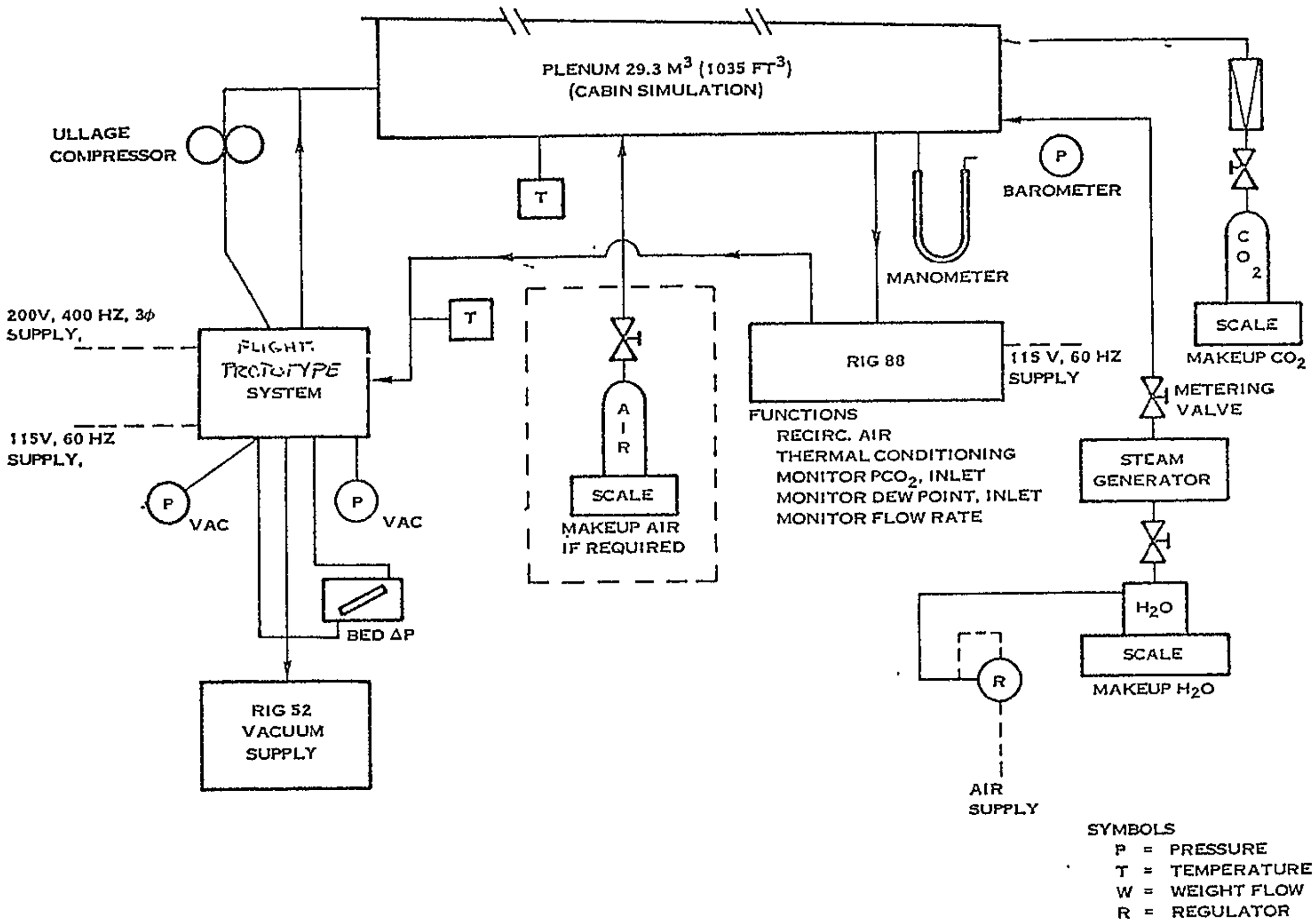


FIGURE 1 - TEST SETUP

FIGURE 2

TEST SUMMARY

Test No.	Environment	Fixed Conditions	Test Variables	Minimum Hours of Test	HS-C Material
1	7 Men, 80°F	80°F DB Temperature 50 cfm Air Flow 58-60°F Dew Point 18/18 Cycle 4.5 mmHg PCO_2	H_2O Feed Rate CO_2 Feed Rate	40	4 Years Old
2	7 Men, 65°F	65°F DB Temperature 50 cfm Air Flow 38-40°F Dew Point 18/18 Cycle 7.0 mmHg PCO_2	H_2O Feed Rate CO_2 Feed Rate	20	4 Years Old
3	7 Men, 80°F	80°F DB Temperature 50 cfm Air Flow 58-60°F Dew Point 18/18 Cycle 4.5 mmHg PCO_2	H_2O Feed Rate CO_2 Feed Rate	60	New
4	7 Men, 65°F	65°F DB Temperature 50 cfm Air Flow 38-40 °F Dew Point 18/18 Cycle 7.0 mmHg PCO_2	H_2O Feed Rate CO_2 Feed Rate	40	New
5	4 Men, 65°F	65°F DB Temperature 50 cfm Air Flow 40/40 Cycle .42 lb/hr CO_2 Feed Rate .78 lb/hr H_2O Feed Rate	PCO_2 Dew Point	20	New